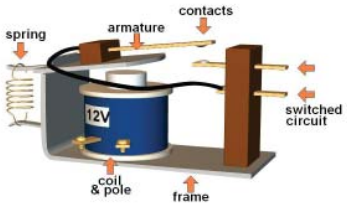



# EM1 – DC Basics

*by Karl Eilers*

## EM1 will cover the following concepts:

- Electrons, protons, fields, charges
- Static and current electricity, potentials
- Math review including scientific notation, basic algebra, symbols used in DC circuits
- Block and schematic diagrams
- Voltage, current, resistance, power, Ohm's and Watt's laws
- Circuit components
- Series, parallel and series-parallel circuits
- Test equipment
- Battery power supplies
- Magnetism and electromagnetism
- Circuit protection, personal safety

### *Give Your Students the Power to Succeed with the Online EM-Series Study Guides*

*The EM-series of study guides give students the knowledge they need to qualify as entry-level technicians, and provides the necessary foundation for further studies in specialized fields. The study guides are closely coordinated with the ETA competencies and exams. Each study guide builds on the one before it. Together they form an efficient, no-time-wasted path to knowledge and certification.*

*The basic goal of the study guides is the same as the goal of the EM certifications themselves: each milestone on the way to eventual mastery is useful in and of itself, giving students immediately useful information and permitting them to earn graduated certifications commensurate with their growing knowledge.*

# Study Guide for ETA-International EM1

# *DC BASICS*

***Welcome to the first of the ETA EM6 training modules, DC circuits. In this module, we will discuss the most basic aspects of electricity and its close cousin, magnetism. You will learn how to analyze DC circuits, make measurements and calculations, and do troubleshooting.***

## *Contents*


INTRODUCTION

1. BASIC ELECTRICITY
2. ELECTRICAL SAFETY
3. DC CIRCUIT MATH
4. OHM'S & WATT'S LAWS
5. COMPONENTS
6. SERIES CIRCUITS
7. PARALLEL CIRCUITS
8. SERIES-PARALLEL CIRCUITS
9. TEST EQUIPMENT AND METHODS
10. BATTERY POWER SUPPLIES
11. MAGNETISM
12. REVIEW

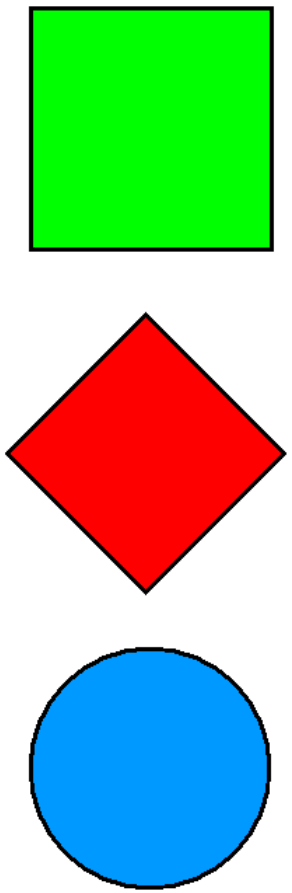
CHARTS, GRAPHS, FORMULAS
(formatted for small screen)
PRACTICE EXAMS
(formatted for printout)


EM1H.2013.1

## *ASPECT RATIO ADJUSTMENT*

**For many of the illustrations in this study guide, it is important for the dimensions and angles to be correct. The green shape should appear as a perfect square, not a rectangle. The red diamond should have 90-degree corners. The blue shape should be a circle, not an oval.**

**If these shapes are not what they should be, please adjust your display settings before you begin this study guide.**



## *BACKGROUND OF EM6 CERTIFICATIONS*
### *by Karl Eilers, EM study guides editor*

For many years, ETA-I has offered a basic certification to entry-level technicians, the **CETa** or **Certified Electronic Technician, Associate** level. After technicians qualify for this certification, they have two years to earn a Journeyman certification in a particular area of electronic technology – fiber optics, alternative energy, residential electronics, etc.

As electronic technology has become more complex and more widespread, ETA has felt the need to increase the depth and breadth of the material covered by the CETa. Also, ETA disliked the traditional "study for years, then get a diploma" approach because students have nothing to show for their effort until the very end. Many students have regular jobs and other commitments and cannot spend all their time studying. Others are aiming for a job that does not require knowledge in all areas.

For these reasons, ETA has decided to offer six **Electronics Module** certifications, **EM1** through **EM6**, each of which represents a worthwhile milestone on the way to overall competency.

As students master each module, they can qualify for a "mini-certification" which testifies to a degree of competence that is genuinely useful for an entry-level technician or as a foundation for further learning. The modules are:

- **EM1 – DC Basics**
- **EM2 – AC Basics**
- **EM3 – Analog Electronics**
- **EM4 – Digital Electronics**
- **EM5 – Comprehensive**
- **EM6 – Wireless**

The CETa exam is in around 75 questions long; *each* of the EM6 exams is about that same size. Thus the EM exams test the student much more thoroughly and add up to very solid evidence that the student has mastered the material.

ETA is not in the business of training or publishing educational material, other than the magazine, "High Tech News," which is published for members and always includes educational articles. However, ETA received so many requests for a CETa study guide that they made an exception; ETA has published a CETa guide for some years now.

Publishing six study guides for the EM6 modules has proved to be a much larger task, and after an abortive start, I took on the project of producing and publishing them myself.

These study guides correspond to the ETA certification competencies. As such they are a cost- and time-efficient way to prepare. I wrote most of the material, so if you don't like it, you know who to yell at. Other material in the EM1 study guide has come from some of the many ETA members who have extensive knowledge of specific topics.

I conceived these study guides for electronic media from the outset, believing that electronic media offers many advantages over print. This study guide is available only as a PDF download in three formats:

- vertical (this version)
- horizontal (for laptops and desktops)
- small screen (for smartphones)

As this is written (1-2013), we do not offer a hardcopy version, because we would have to charge much more than it will cost you to print it yourself and have it spiral bound at Staples or OfficeMax If you shift the text to one side when you print, you'll have space to make notes in the margin.

For this study guide, math is pretty simple: fractions and decimal fractions, scientific notation, prefixes (e.g. kilo, mega), graphs, and some miscellaneous topics. If your math is a bit rusty, you'll have a chance to review in chapter 2 before you have to use any of it.

# EM1 Chapter 1
# BASIC ELECTRICITY

*by Karl Eilers*

*Objectives covered in this chapter:*

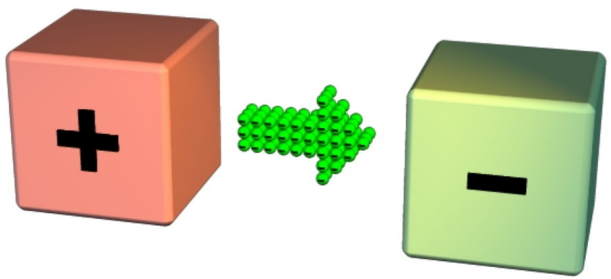
- *Describe the causes and effects of static electricity.*
- *Describe atomic structure and its importance to electronics technology.*
- *Explain the electronic physics terminology of work and energy, the different forms of energy and their applications.*
- *List the most common components.*
- *Discuss basic circuit concepts.*

## HISTORY AND DEFINITION OF ELECTRICITY

**Electricity is the existence and movement of electrical charges.** It is one of the four fundamental forces, the others being gravity, the strong nuclear force, and the weak nuclear force. The word “charge” as it applies to electricity comes to us from Ben Franklin.

Scientists before Franklin knew that there are two kinds of charges. Experiments showed that these charges are opposite in every way, so Franklin gave them the names **positive** and **negative.** Every object, whether pen, pop bottle or person, is full of both kinds of electric charges. If these charges are equal and balanced, the object has no charge overall. But if an imbalance between the two charges is created, the object acquires charge.

Franklin showed that, though there are two kinds of charges, only one is a fluid. If you pour an excess of this fluid into an object, or remove some of the fluid from it, the object's overall charge becomes unbalanced. When an object is in this state, according to Franklin, it is **charged**.




**CHARGE TRANSFER**

We now know that the “electric fluid” consists of **electrons**. In the illustration to the left, the green spheres represent electrons which are made to move from the left object to the right object by friction or some other means. This causes a charge imbalance in both objects. Electrons are negatively charged, so the excess of electrons in the right object gives it an overall negative charge. The positive charge on the left object is caused not by an excess of positive charges, but a scarcity of negative charges.

If you bring oppositely charged objects near or in contact with each other, a spark jumps and the objects lose their charges. The spark is the electric fluid flowing from one object to the other, returning both objects to equilibrium. They are then said to be **discharged**.

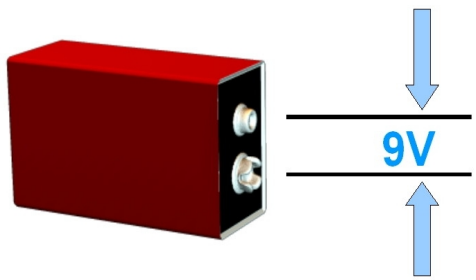
## STATIC AND CURRENT ELECTRICITY

The electricity of charged objects is what we call **static electricity** - "static" because the charge on an object is stationary, not moving. Rubbing wool on wax, for example, scrapes electrons off the wool and onto the surface of the wax. The wool becomes positively charged, while the wax becomes negatively charged. (This is called the **triboelectric effect** – tribology is the science of rubbing surfaces.) If the two objects are then pushed together without rubbing, the excess electrons travel from the wax back to the wool and the charges are neutralized.

The only thing scientists of Franklin's time could do was charge and discharge objects. But in 1800, ten years after Franklin's death, a gentleman named Volta invented the chemical **battery,** which provided a continuous supply of electrical charge.

When Volta invented the battery, humanity hit the jackpot. The availability of a continuous supply of electricity launched the parade of innovation that has culminated in the modern electronic age.

In contrast to static electricity, which involves charging and discharging objects, continuously-flowing electricity is called **current electricity**.




**POTENTIAL**

A battery has two **terminals**. A chemical reaction in the battery generates a difference in charge between these terminals, which is referred to as an electrical **potential**. As soon as some of this charge is drawn off, the chemicals make more.

It is important to understand this fundamental difference:

- Static electricity involves charges *on and in* objects – imbalances in the number of electrons and protons, in an absolute sense.
- Current electricity involves differences in charges between objects. A potential is the charge difference between two points. The absolute charge at either point is usually unimportant.

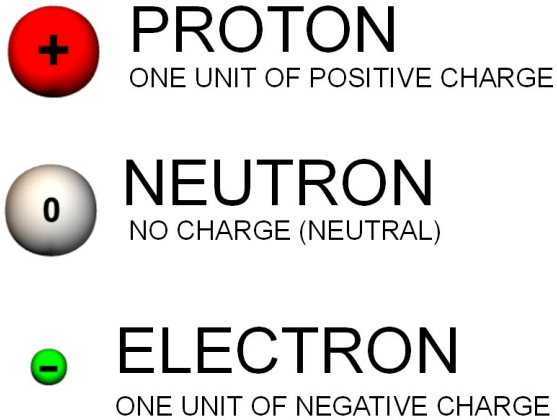
## ATOMIC THEORY

We still haven't adequately said what electricity is. To do that, we have to look at atoms and molecules. Though technicians don't usually work at an atomic level, an understanding of atomic theory will pay off in surprising ways. Electricity is invisible. Even when you see lightning, you're not seeing electricity; you're seeing superheated air and water vapor. It is important to develop the ability to visualize electricity, and knowing some atomic theory helps.

We will be using the atomic model developed by Niels Bohr in the 1920s. Scientists now understand that actual atoms are much more complex. But the **Bohr model** accurately describes the way electricity works, which is what we're interested in; that's why it was accepted as correct for so many decades. Technicians and engineers continue to use it successfully, as a kind of mental shortcut.

In the Bohr model, atoms are made of **protons**, **neutrons** and **electrons**. Protons and electrons are electrically **charged**. Neutrons carry no charge and, most of the time, are not involved in electricity.

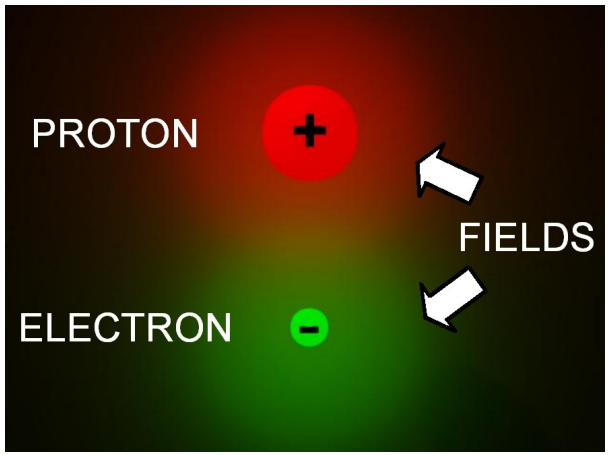
The proton carries one unit of positive charge, while the electron carries a unit of negative charge. Think of this as the "yin" and "yang" of subatomic particles. The charges are always the same strength - there is no such thing as a "stronger" or "weaker" proton or electron. The charges of the proton and electron are equal to each other in strength, but of opposite polarities.

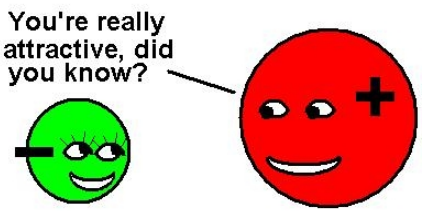



## ELECTRICAL FIELDS

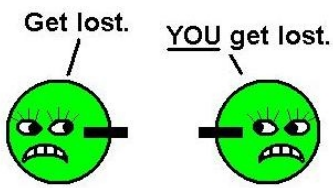
The practical usefulness of electrical charges comes from the fact that charged particles have **fields**.

You know that magnets have magnetic fields, and because of these fields, magnets push or pull on each other at a distance. Electric charges have **electrostatic fields**, and like magnets they act at a distance, pushing and pulling on each other.



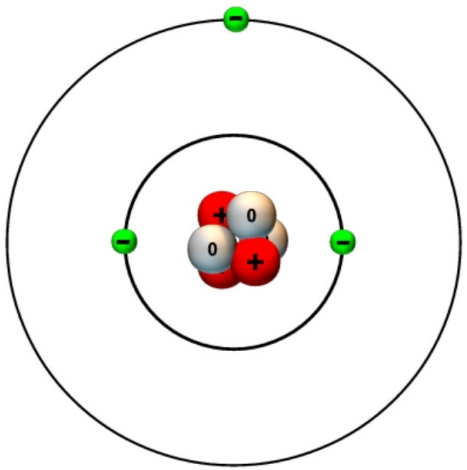




Particles with opposite charges, i.e. a proton and an electron, attract each other.




Particles with the same charge, i.e. two protons or two electrons, repel each other.

Though protons' and electrons' charges are equal, their masses are not. Protons and neutrons are about 2,000 times more massive than electrons. For this reason, protons and neutrons clump together in a **nucleus** and pretty much stay in one place while the electrons revolve around them, as planets revolve around the sun.



**BOHR MODEL**

It may occur to you to ask, why do the protons clump together? Don't they repel each other as electrons do? Yes, they do. However, two of those other fundamental forces, the “strong force” and the “weak force,” which only work over very short distances, are strong enough to hold protons near each other in spite of their repulsion.

Different kinds of atoms correspond to different **elements**. The number of protons determines which element an atom is. In a normal atom, the number of electrons equals the number of protons. One proton, one electron = hydrogen. Two protons, two electrons = helium. Three protons, three electrons = lithium. The number of protons and electrons, especially in the outer orbit, determine an element's electrical behavior and how it reacts chemically.

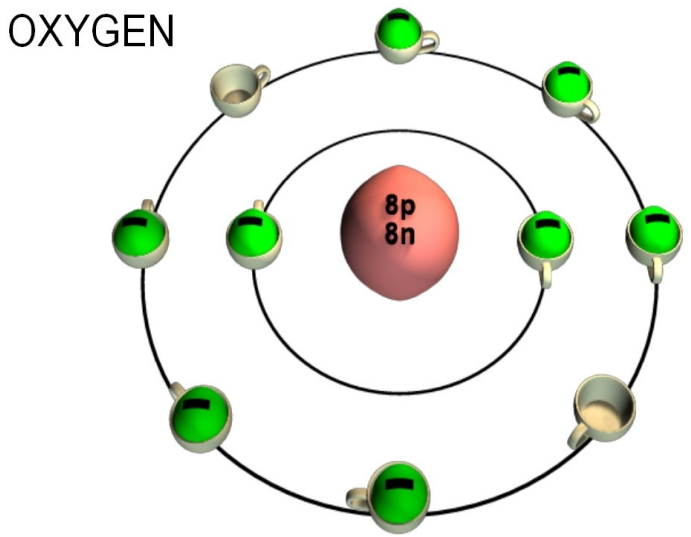
## ELECTRON ORBITS

A planet's orbit can be any distance from the sun, but electrons can only occupy orbits at *specific* distances from the nucleus. An electron cannot follow an in-between orbit. Each orbit represents an **energy level**, with the electrons in more distant orbits possessing higher energy.

Because electrons repel each other, there is a limit to how many each orbit can hold. The innermost orbit can contain either one or two electrons, no more. The illustration on the previous page is a representation of a Lithium atom, with three electrons – two in the inner orbit, filling it, and a third taking a place in the second orbit.

An orbit could be represented by a ring of cups, each of which can hold an electron. The first orbit can only contain two electrons, so there are only two cups. The second orbit has eight cups.

The illustration below is a representation of oxygen, with a positively charged lump in the center, representing a nucleus consisting of 8 protons and 8 neutrons. There are 8 electrons revolving around the nucleus in two orbits.




There are two cups in the inner orbit, both full. There are 8 cups in the outer orbit, with 6 electrons and 2 empty cups.

If we added a neutron and a proton to the nucleus, and filled one of the empty cups with an electron, our oxygen atom would become a fluorine atom. If we did it again, the atom would become neon and all the cups would be filled. This is as far as we can go with two orbits.

More complex atoms with more electrons require a third orbit. Sodium has eleven electrons - two in the first orbit, eight in the second, one in the third. As we get to larger and larger atoms, this cycle repeats (with some hiccups, which we're not going to bother about) up to a maximum of seven electron orbits. The largest atoms are so unwieldy they can't hold together. From time to time, they eject particles, and eventually turn into other elements entirely. This is “radioactive decay.”

Each proton in an atom has just enough positive charge to attract and hold one electron, which is why a “normal” atom has equal numbers of protons and electrons. Thus a normal atom has no overall charge. That’s why objects, which are made of gazillions of normal atoms, are normally not electrically charged.

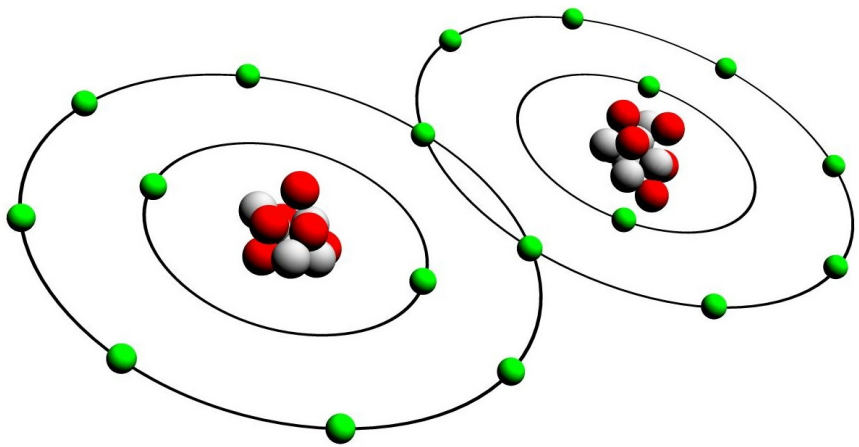
Atoms can become abnormal. An atom can lose an electron or gain one, becoming charged. A charged atom is called an **ion**. When an object acquires a charge, it's because some of its atoms have a shortage or surplus of electrons. If a doorknob, say, has a positive charge, that means some of its atoms are missing an electron.

## MOLECULES

Atoms like to have their orbits filled. They do this by combining into **molecules**.

Let's look at oxygen for example, which has six electrons in an orbit that could hold eight. That represents two empty cups. If the oxygen atom combines with two hydrogen atoms, which have one electron apiece, those two empty cups are filled and we have $H_2O$, which is water.

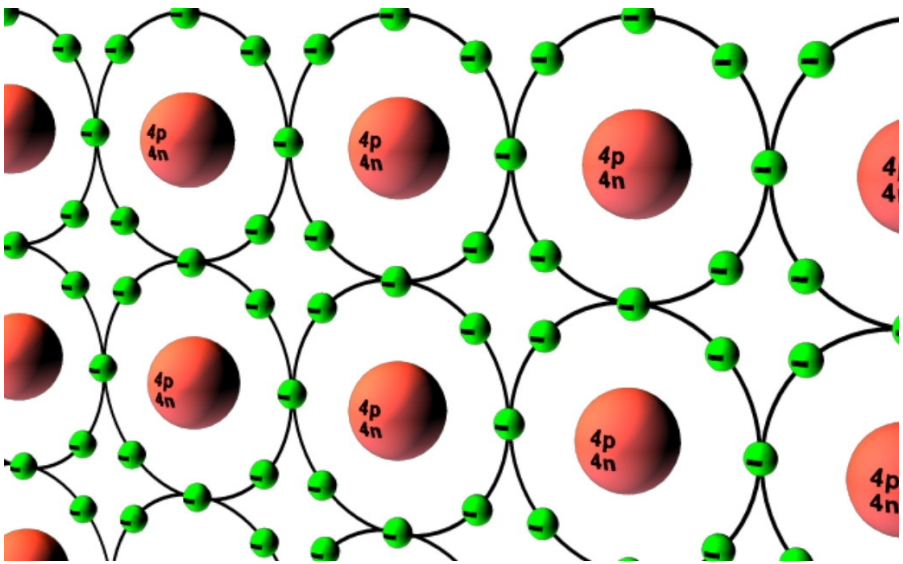
Or, if two oxygen atoms combine, each sharing one electron, we get a molecule of oxygen, $O_2$.



**OXYGEN MOLECULE**

## ELECTRON MOBILITY

We've been talking about electrons as if they were captive, and always stayed with their “home” atoms and molecules. In many cases this is not true. Atoms with only a few electrons in the outer orbit have enough empty spaces for each atom to combine with a lot of other atoms. This means a lot of electrons are shared throughout the material. (The illustration below is a very simplified model to illustrate the concept, not at all accurate.)




**SHARED ELECTRONS**

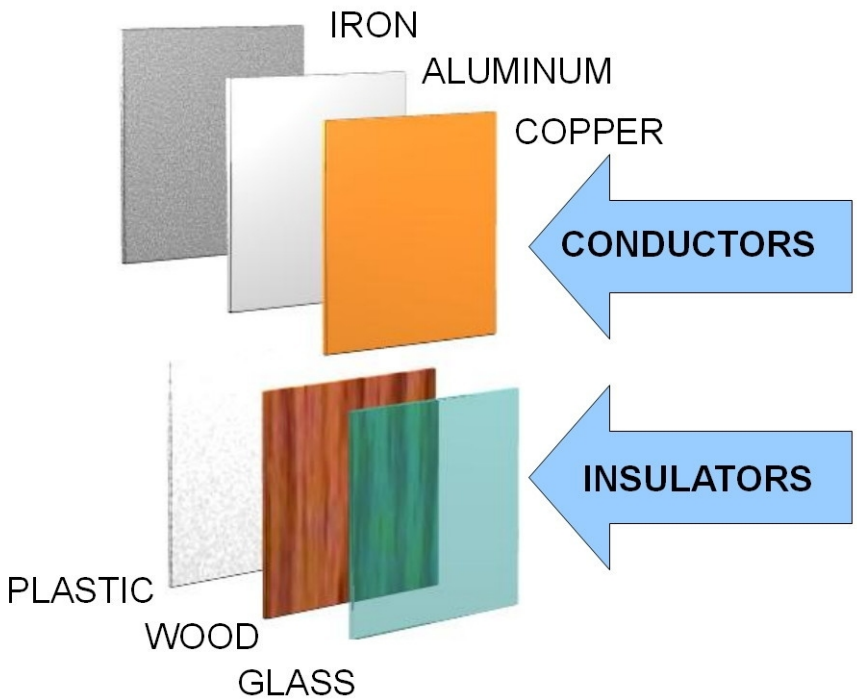
When a lot of electrons are shared, an interesting thing happens. The shared electrons are free to migrate among atoms. And in fact they do, all the time, due to normal molecular vibration.

Usually, this motion is random and goes in all directions, so the sum of all the electron movements is zero. But if an electrical potential is connected across this material, electrons will move away from the negative region and toward the positive region.

This behavior is no mystery; it simply comes from the fact that a negatively charged electron is repelled by another negative charge and attracted to a positive charge. This is the mass electron migration we call **current** - the flow of electricity.

## CONDUCTORS, INSULATORS AND SEMICONDUCTORS

Not all materials are alike. In some, outer-orbit electrons can move around. In others, each electron is bound to a particular atom or molecule, and current normally will not flow. From an electrical standpoint, this is the most fundamental distinction among different kinds of materials.




Most materials will fall definitely into one group or the other. A material that permits current to flow easily is called a **conductor**. Metals, and some other materials, are conductors. A material which does not permit current to flow is called an **insulator.** Materials like glass, rubber and most plastics are insulators.

By skillfully using conductors and insulators, we get electricity to go where we want it to go (like from the power plant to your table saw), and keep it from going where we don't want it to go (like from the table saw to your fingers).

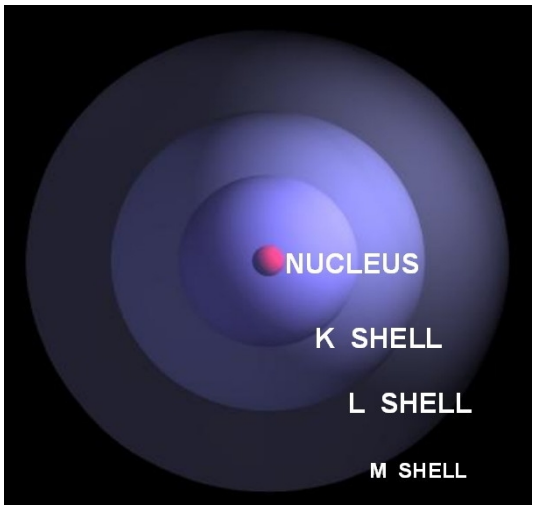
Some materials, like carbon, are conductors but not good ones. You'd think that would make them useless, but in fact we absolutely depend on them. Poor conductors are used to control and limit electrical current.

There is also a special class of materials called **semiconductors** which can be good insulators, good conductors, or anything in between depending on chemical impurities and structure. We can make semiconductors act like valves which open or close in response to electrical control signals. One type of semiconductor valve is found by the billions in a computer. It's called a transistor.

Before we leave atoms and molecules, let's acknowledge that we've been dealing with a *very* simplified model. For one thing, I've been showing atoms as 2-dimensional objects for convenience. Atoms are of course 3-dimensional. The electron orbits are usually thought of as “shells” similar to nested ping-pong balls.

And that's just the beginning. We now know that electrons aren’t really hard little marbles, their orbits aren’t circular, and their position at any moment cannot be predicted even in theory.

I'm only telling you this because I don't want people coming back and saying,"You lied, the Bohr model is false!" I know it's false – or rather, it is incomplete, like Newton's laws of physics. It holds as much truth as the science of the 1920s permitted Bohr to discover.




**ELECTRON SHELLS**

However, it describes electrical behavior so well that technicians and even most engineers continue to use it as a mental shortcut, and never bother thinking of atoms in their full complexity. And that's what we will do as well. So much for atoms and molecules. Now, what's coming up next is really, really, really important.

**If you were in the room with me, this is where I'd whack you over the head to be sure I've got your full attention. If you're not fully awake, get a cup of coffee. The next few paragraphs lay out the four most fundamental characteristics of electricity, and how these characteristics interact.**

## CURRENT, EMF, RESISTANCE

We're going to look at three of these characteristics first:

- **current**, which we've already mentioned,
- **EMF**, and
- **resistance**.

We will also learn the units which are used to measure these characteristics.

**<u>CURRENT</u> is the flow of electricity from one place to another. It is Franklin's "electric fluid." It consists of negatively-charged electrons moving from atom to atom, and under some conditions, through space.**

In equations, current is represented by **I** for **Intensity**. "C" can't be used because there's something called "capacitance" that it's used for instead.

The unit of measurement for current is the **Ampere**, or **Amp** for short, after a gentleman who discovered much of what we know about electromagnetism. Ampere is abbreviated **A**, as in I = 2.5A. A current of one amp is a little over 6,000,000,000,000,000,000 electrons flowing past a point per second. That quantity is known as a **Coulomb**.

There are two kinds of current. The kind of current we're dealing with in EM1, **Direct current** or **DC**, flows continuously in one direction. **Alternating current** or **AC**, which we study in EM2, flows alternately back and forth. It seemed to early researchers, famously including Edison, that DC was the way to get power from one place to another, and AC was useless. But then Nikola Tesla came along, showed what AC is good for, and invented our modern electrical system.

However, most electronic circuitry still operates on DC. Where the operating power comes from an AC power line, the equipment includes AC-to-DC conversion circuitry, which we'll study in EM2. Combinations of AC and DC are also possible, as we'll see when we get to EM3, Analog Basics.

Current doesn't flow by itself. Something has to make it flow. Namely:

**ELECTROMOTIVE FORCE, or EMF for short, is what causes current – it's the force that makes electricity flow.**

Early researchers gave it that generic name because they knew it had to exist, but they didn't know what it was. We now know that it's simply the result of the fields associated with a difference in charges, acting upon electrons. If you connect a lamp across a battery, you have created a conductive path for electrons. They will be drawn toward the positive battery terminal and pushed away from the negative one.

The unit of measurement for EMF is the **Volt**, after Mr. Volta, the inventor of the battery. It is abbreviated **V**. Because "EMF" is a bit cumbersome, most people say "**voltage**" instead.

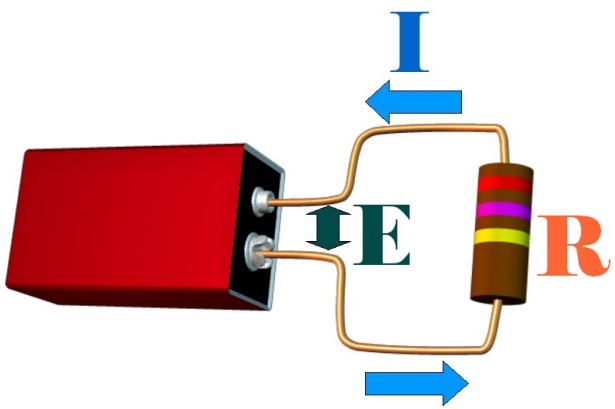
In calculations, either "E" for EMF or "V" for voltage can be used. "E" tends to be used in connection with static electricity, while most people use "V" in connection with current electricity. Again, in current electricity, voltage is a differential quantity, a potential between two points.

**RESISTANCE is a kind of "friction" that interferes with the flow of electrical current.**

Resistance causes problems, because even the best conductors have resistance, making it hard to deliver large amounts of electricity from one place to another. But resistance is also necessary, because we need to be able to control the amount of current flow, and resistance is the primary tool for doing that. Without resistance, even a small voltage would result in an infinitely large flow of current.

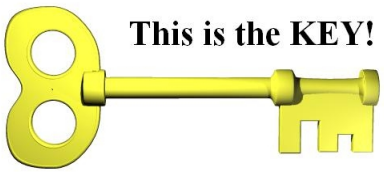
In equations, resistance is represented by "**R**." The unit of measurement is the **Ohm**, after the man who figured out the most important mathematical relationship in all of electrical engineering. The abbreviation is not "O" because that would be confused with zero. Instead, the Greek letter Omega, **Ω**, is used.

## THE E/I/R RELATIONSHIP




Current, voltage and resistance are linked in the most fundamental way. Their interaction is mathematically described by an equation called **Ohm's Law**, which is discussed in chapter four. But you don't have to know the

actual numbers to get a general idea of how current, voltage and resistance work with each other. It's just common sense. The amount of current flowing through a conductor depends on how hard voltage is "pushing" and how hard resistance is resisting. Increase the voltage, and current goes up. Increase resistance, and current goes down. This means you can make the current any value you want by your choice of voltage and resistance.




Ohm's Law is to an engineer or technician what a trowel is to a bricklayer. It's the basic tool.

## POWER

**<u>POWER</u> is the fourth basic aspect of electricity. Mathematically, power is voltage times current.**

In equations, power is represented by the letter "**P**". Its unit is the **Watt**, after James Watt, who invented the steam engine that powered the industrial revolution. The abbreviation is **W**, as in P = 50W. People often use the term **"wattage"** to describe electrical power.

"W" could also stand for "work" (and does, in physics) because it is power that gets things done. Voltage alone, or current alone, do not accomplish anything. It is the *combination* of voltage and current that represent power.

Physically, **power is the rate at which energy is consumed.** Energy can take many forms: heat, light, noise, radio transmissions, horsepower, and so on. Energy can be converted from one form to another. For example, a radio station's signal represents the conversion of a coal fire's heat to a boiler's steam pressure to a turbine's rotation to a generator's electricity to a transmitter's electromagnetic radiation.

The chart on the next page summarizes the basic electrical units we've introduced so far. The chart is also found in the printable review, chapter 12. You should go to chapter 12, print out the chart, and keep it in front of you until these units are completely familiar.

| *PROPERTY* | *SYMBOL* | *UNIT* | *SYMBOL* | *FUNCTION* |
|---|---|---|---|---|
| **EMF, Electro-Motive Force** | **E or V** | **Volt** | **V** | **Force that makes current flow** |
| **Current** | **I** | **Ampere (Amp)** | **A** | **Flow of electrons** |
| **Resistance** | **R** | **Ohm** | **W** | **Limits current** |
| **Power** | **P** | **Watt** | **W** | **Work, E x I** |

As we'll see in chapter 4, there's a Watt's Law that combines voltage, current, resistance and power calculations. There are also visual memory aids to help you remember what's what. Or what's Watt, as the case may be.

## JOULES & ENERGY

Wattage is an instantaneous quantity. A specific voltage and a specific current result in a specific power at a specific instant. But the amount of energy produced or consumed depends not only on the power level, but also the time period. Obviously, if a generator produces a watt for an hour, that's more energy than if it produces a watt for a minute.

The basic time-related power unit is the **joule**, which is one watt of energy for a duration of one second. When I say "power," remember that various kinds of power – heat, light, motion etc – are convertible from one form to another. This allows designers of generators, solar panels and the like to determine how much of some other kind of energy is needed to make a joule of electricity.

Joules are also called **watt-seconds**. Larger quantities are called watt-hours (a watt produced or consumed continuously for an hour) and kilowatt-hours (a thousand watts over a period of an hour), which you see on your electric utility bill.

## ELECTRONIC DIAGRAMS

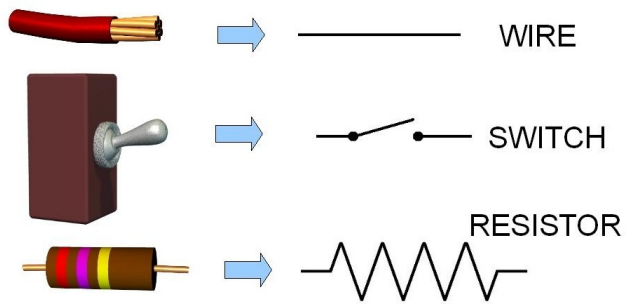
We're about to start drawing simple electrical systems. The two most common kinds of diagrams are **block diagrams** and **schematic diagrams**. Block diagrams show the major functional units in a system – microphone, amplifier, camera, video screen, transmitter, antenna – so we can study signal flow. Schematic diagrams show actual parts.

We're going to be drawing schematic diagrams. But we're not going to be drawing pictures of the actual parts. Drawing a switch, for example, takes way too much effort. Besides, there are hundreds of different kinds of switches, but their function is always the same, and it's the function we're interested in. So instead of drawing physical parts, we draw simplified functional symbols.

## SCHEMATIC SYMBOLS

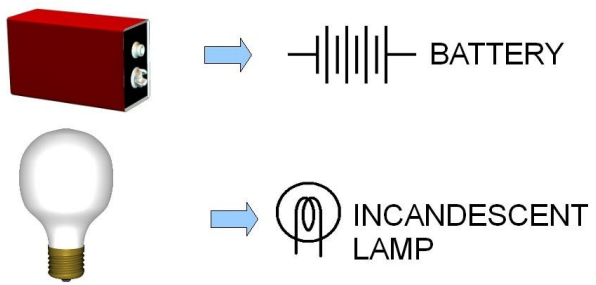
A wire isn't considered a “part,” strictly speaking, but we need wires to connect the parts, and we have to draw them in the diagrams. The symbol for a wire is just a line.

A switch is a pair of dots with a line at an angle. The idea is that the line can be moved to create a continuous electrical path or break it. Think of a big old horror-movie switch.




A resistor, which has a lot of resistance lumped in one part, is a wiggly line. If you've looked at the glowing element in a space heater, you know where they got the idea for that one.

A battery is alternating long and short lines. One long and one short line represent a single cell, like an AAA battery.




A bunch of them represent a higher-voltage battery, which is made by stacking a number of cells. Volta would have known at a glance what this symbol represents.

An incandescent lamp is a loop inside a circle.

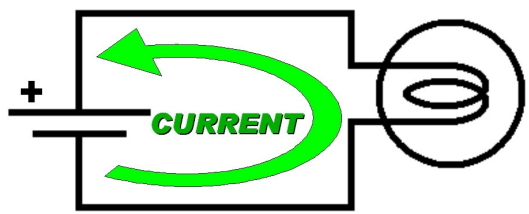
Incandescent lamps are becoming obsolete, but we're going to talk about them because they're easy to understand. An incandescent lamp is just a white-hot resistor in a glass bulb with no oxygen in it, so it can't burn up.

For conceptual simplicity, we think of these as “ideal” components: wires with no resistance, resistors that always have the same resistance under all conditions, switches that are perfect conductors when they're conducting and perfect insulators when they're insulating. Thinking in these terms isn't always the best practice in the real world. The difference between an ideal component and a real one is often responsible for that funny burnt smell just before a piece of equipment stops working. But we will consider the parts in our diagrams as ideal components, just to keep the concepts clear.

## CIRCUITS

We're now ready to talk about circuits. Static electricity involves charges moving *from* one object *to* another. Current electricity involves charges moving from the negative terminal of a power source (say, a battery) *through* a conductor and, usually, at least one electric gizmo, and then back to the positive terminal of the power source.

In other words, the current travels in a loop or **circuit** like a circuit judge visiting a series of courthouses. This complete-circuit concept is of fundamental importance! Current electricity doesn't flow *to* or *from* anywhere, but *everywhere at once*. On its way through, it does useful work – lighting a lamp, turning a motor, heating a furnace element.




**COMPLETE CIRCUIT**

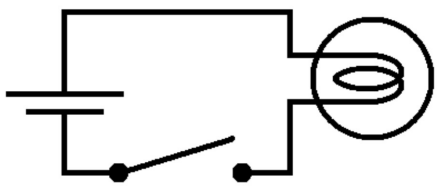
Above is a very simple circuit consisting of a battery, an incandescent lamp, and wires to connect them together. This circuit might represent a flashlight. Electrons move from the negative side of the battery, through the first wire, through the lamp, through the second wire and back to the battery. Current is determined by the voltage of the battery and the resistance of the lamp.

## SERIES, PARALLEL AND SERIES-PARALLEL CIRCUITS

We're just going to briefly introduce these circuits here; we'll study them in greater detail after we’ve mastered Ohm’s Law.

In this study guide, we've devoted three entire chapters to series, parallel and series-parallel circuits and how to analyze them, because these circuits are the basic building blocks of all electronic equipment.

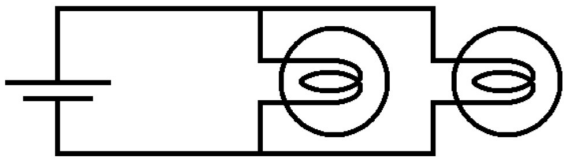
Let's improve on the flashlight we just made. It would be nice to be able to shut the flashlight off. We can do that by breaking one of the wires, leaving an air gap between the ends. Air is a very good insulator. But would be inconvenient to join and unjoin the wires all the time, so let's connect the ends of the broken wire to a switch, as shown at right. Now we can turn the lamp on or off conveniently.



**SERIES CIRCUIT**

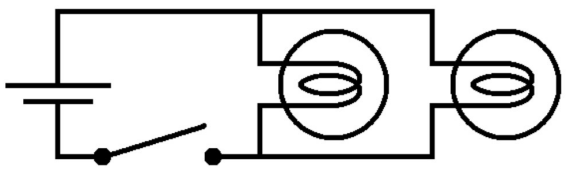
What we have just done is create a **series circuit.** Electricity passes first through the switch, then through the lamp, one after another. In other words, it passes through a series of components. There could be additional components in the circuit. A string of incandescent indoor holiday lights is typically 25 lamps in series.

In the circuit above right, there are two current paths. Current flows through both lamps at once. This is a **parallel circuit.** Outdoor holiday lights are wired in parallel.



**PARALLEL CIRCUIT**

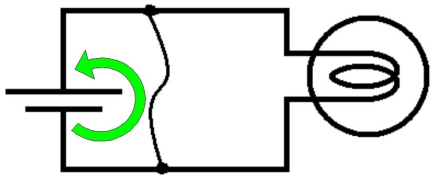
If we put a switch in one of the wires to turn the lamps off, we have a **series-parallel circuit** where the switch is connected in series with the paralleled lamps.



**SERIES-PARALLEL CIRCUIT**

In an office building, if you flip a light switch and 24 lights come on, that's a switch and 24 lamps wired in series-parallel.

If a connection like that shown at right is accidentally made, bypassing the current-limiting lamp, we have a **short circuit.** The current flow would be infinite if these were truly ideal parts – if there were no resistance in the battery and wires. In practice, the wires and the power source have some resistance, but the current can still be high enough to be dangerous – ask any firefighter.



**SHORT CIRCUIT**

## EARTH AND CIRCUIT GROUNDS

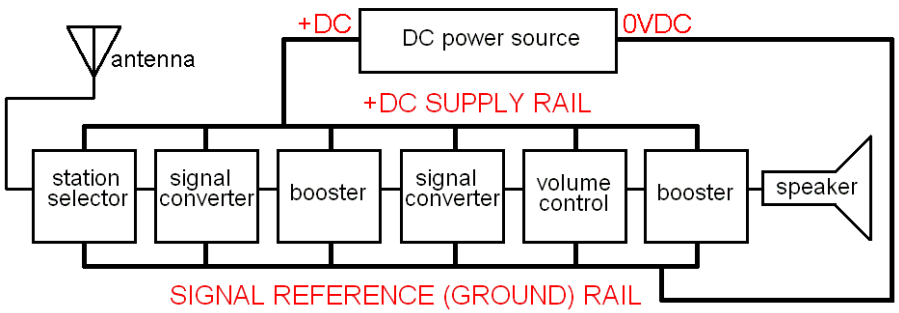
In a simple circuit like a flashlight, it's enough to say that there's "X" voltage across two points. However, in most of the equipment and systems you'll encounter, with lots of different voltages in different places, a single point will be chosen as a reference and defined as "zero volts." Then all the other voltages in the system will be measured against this point. This point is called **ground**, or in England, "Earth."

The ultimate ground reference is the Earth itself, which is almost exactly neutral in charge. Damp earth is conductive, and you make a connection to it by driving a metal stake deep into the ground. A wire connected to this stake is an **Earth ground connection**. Anything connected to this wire is said to be **grounded**, or in England, "Earthed."

In a piece of equipment, any point can be chosen as the ground, and then all voltages in the system are measured against that point. This is called the **equipment** or **system ground**.

Some points make more sense than others. Usually, one terminal or the other of the power supply is chosen as the reference. The ground then serves as the main connection to one side of the DC supply. In this case it may also be referred to as the **common**.

The reason for a common reference is to allow different parts of the system to work together. The illustration on the next page, for instance, is a block diagram of a portable FM radio. Each block processes the signal and passes it on to the next block. For this to work, signals must be referenced against the same point everywhere. This means every functional block must be connected to the same reference. In this example, the reference is a ground wire connected to all the blocks. The ground is also DC common. There is no Earth ground.




**FM RADIO**

Different kinds of grounds have different schematic symbols. If a diagram is drawn according to the "rules," it will show the point where circuit, chassis and Earth ground interconnect, assuming all three are present.

Those who draw diagrams often confuse these symbols, either because they don't know them or out of habit – older engineers and techs use the one on the right for circuit grounds and many people use the one in the middle for Earth ground. By the time you're a trained tech, you'll understand circuit functions well enough that this won't throw you.

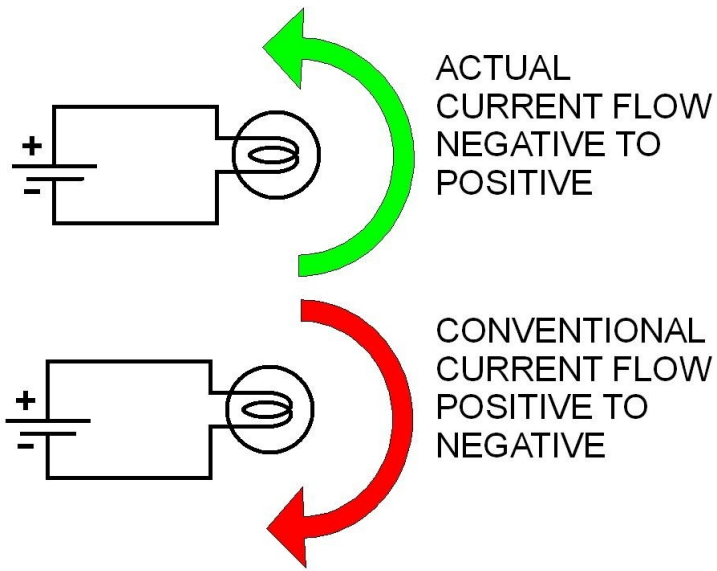
## "RAILS"

The DC and ground wires that serve every part of a piece of electronic equipment are often called **rails**, as in "supply rail" and "ground rail." They're a lot like the water and drain pipes that are connected to every sink, shower, and bathtub in a building.

## THE POSITIVE CURRENT CONVENTION

When Ben Franklin rubbed wool on wax, he named the resulting charge on the wool "positive" and the charge on the wax "negative" because he guessed the wool had rubbed electric fluid off the wax, as it would with paint. He guessed wrong; electric fluid is negative and the movement went the other way. And that mistake is still causing problems to this day.

Many people find it hard to think of current as negative charges (electrons) flowing from negative to positive. It's much more natural to think of current as positive charges flowing from positive to negative, and even though it's false, it almost always works. This is called the **positive current convention**, convention meaning an agreed-upon custom like shaking hands or saying "gesundheit." We call this current **conventional current**.




Getting everybody to choose one or the other and stick with it has proved impossible. Often, a particular school's instructors disagree among themselves. There is at least one electronics textbook published in two versions, an electron-flow based one with a white cover, and a conventional-current based one with a blue cover.

We're like Canadians, who have two official languages, and probably always will, because settling on one language is politically impossible. The Canadians live with their compromise, which is inconvenient but workable, and the only available option under the circumstances. Likewise, we continue to juggle electron-flow and conventional-current ideas in our minds, and learn to switch back and forth, using whichever suits a particular situation. It is often helpful to think of *electrons* flowing from negative to positive but *current* flowing from positive to negative.

Since an industry-wide consensus will probably never be reached, in these study guides I'm going to flip back and forth so you will become comfortable with both ways of looking at current, and be able to communicate with any tech you meet. It will probably become obvious that my own preference is conventional current, but there are things, like vacuum tubes, that only make sense when considered from the

standpoint of actual negative-to-positive electron flow. Canadians who become fluent in both French and English have an advantage over those who don't, and techs who learn to work equally well with electron flow and conventional current have a similar advantage.

## STATIC ELECTRICITY AGAIN

So, does static electricity play any part at all in electronics? Yes, unfortunately. It's always being generated by accident, as people shuffle across carpets, put on and take off

clothing, wipe things off with dry rags, and so on. When these static charges discharge into electrical equipment, they add noise to audio and video signals, corrupt digital data, and occasionally damage the equipment. And let's not forget about the largest static discharge of all, lightning, which does a great deal of damage.

As you will discover beginning with EM3, creating and controlling electricity is only half the battle. The other half is keeping it from being ruined by other sources of electricity that aren't supposed to be mixed with it. Engineers and techs need to pay almost as much attention to the latter as the former.

## WORD LIST

Throughout these study guides, the names of important ideas will be shown in **bold** the first time they occur. I assume you'll learn them as we go along, and each study guide has a review chapter where they're summarized.

However, the concepts in this chapter are so fundamental to everything that follows that I've compiled the word list to the right. As you go through the words, pretend you're being asked to explain each one. When you encounter a word that you couldn't confidently explain to someone else, go back and review.

***End of chapter 1***

| | |
|---|---|
| **CHARGE** | **CURRENT, I** |
| **ELECTRICITY** | **AMPERE, AMP, A** |
| **POSITIVE** | **ELECTROMOTIVE FORCE** |
| **NEGATIVE** | **EMF, E** |
| **NEUTRAL** | **VOLTAGE, V** |
| **FIELD** | **RESISTANCE, R** |
| **ATOM** | **OHM, W** |
| **ELEMENT** | **RESISTOR** |
| **PROTON** | **POWER, P** |
| **NEUTRON** | **WATT, W** |
| **ELECTRON** | **JOULE, WATT-SECOND** |
| **ION** | **DIRECT CURRENT, DC** |
| **DISCHARGE** | **ALTERNATING CURRENT, AC** |
| **MOLECULE** | **CIRCUIT** |
| **POLARITY** | **SERIES CIRCUIT** |
| **POTENTIAL** | **PARALLEL CIRCUIT** |
| **CONDUCTOR** | **SERIES-PARALLEL CIRCUIT** |
| **INSULATOR** | **CLOSED CIRCUIT** |
| **SEMICONDUCTOR** | **OPEN CIRCUIT** |
| **STATIC ELECTRICITY** | **SHORT CIRCUIT** |
| **CURRENT ELECTRICITY** | **SWITCH** |
| **GROUND** | **MAKE** |
| **COMMON** | **BREAK** |
| **RAIL** | **POSITIVE CONVENTION** |

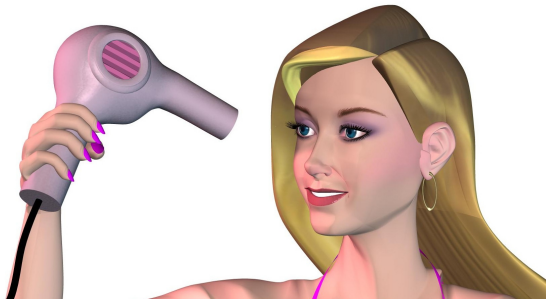
# EM1 Chapter 2
# ELECTRICAL SAFETY

**by Karl Eilers**

*Objectives covered in this chapter:*

- *Describe personal safety precautions for working with electrical and electronic devices.*
- *Describe the human physiological reactions caused by electric shock.*
- *List various degrees of current the human body can tolerate.*
- *Explain the concept of First Aid and its particular importance to workers in electrical and electronic fields.*
- *Explain precautions needed in the area of electronic safety. Describe the different classes (A, B, C, D) of fires and the types of extinguishers used to fight them.*

Before we go any farther, we're going to talk about safety. Every time a person plugs in or uses an appliance, they're holding death in their hand. They hardly give it any thought, because appliances are carefully designed to keep the electricity they run on away from the people who use them. Over the years, manufacturers have gotten very good at this. Today, an appliance has to be extremely defective or its user extremely stupid for an accident to happen.



Until now, you have been one of those well-protected users. But you're about to make a major life change, and you should stop and think about this until it sinks in. There is no way to keep electricity away from the technician who works with it. You're about to step into the lion's cage. You're going to do it for a living. So you're going to have to learn to treat electricity with more respect than you have in the past.

If you're a young adult preparing for a career, you have probably spent more years inside schools than outside. School is a place where mistakes can be corrected, you almost always get a second chance (and a third, and fourth), and if all else fails, you can take a course over again or go back to school later. In other words, school is a place where actions do not have irreversible consequences. The intent is to give people a place where they don't have to learn about real life the hard way.

The result, often, is that they don't learn about real life at all. In real life, especially when working with electricity, actions have consequences, and you can very easily get yourself into a jam there's no way out of. You may not even have time to think, “Oh crud, I've screwed up,” before the Grim Reaper takes you away. You are training to work, on a daily basis, with a force of nature that doesn't see, doesn't think, doesn't understand that you're too young to die.

So, how does it happen that the vast majority of electronic technicians live to a ripe old age? They develop safe work habits, and practice them until they become as automatic as breathing.

## KINDS OF WORK-RELATED DANGERS

The most important part of coping with dangers is simply being aware of them. Accordingly, I've compiled a list of some of the most common work-related dangers, divided into four categories:

1. Electrocution and electrical trauma
2. Other electrical dangers (overheating equipment, fire etc.)
3. Non-electric dangers from electronic equipment (fumes, x-rays etc)
4. Other work-related risks

Many of the dangers have to do with AC power. We won't be talking much about AC until EM2. However, AC and DC pose similar dangers, so we're going to include the safety aspects of working with AC here. Also, this will give you an early start on developing a safety-oriented mindset with respect to certain special dangers posed by AC.

We're going to look at the dangers first. Then we will study preventive measures. Finally, we'll study first-aid and emergency procedures.

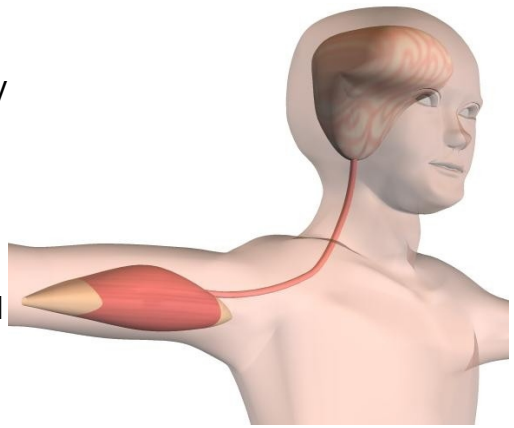
There is no way I can foresee or list every danger. It is up to you to be alert on the job and see to your own safety.

## ELECTROCUTION AND ELECTRICAL TRAUMA

The most obvious danger is electrocution. The human body is over 80% salt water, which is a conductor. (In England, theaters once used salt-water tanks as lamp dimmers.) Electricity can easily flow through a human body, which isn't designed to tolerate it.

If you get enough current flowing, it can kill you through simple heating. As in boiling or frying. Or, if the voltage is high enough, parts of your body just explode or carbonize. Sorry about that, but there's no way to make electrocution pretty.

But electricity has a sneakier way of killing. It just shuts your muscles down.



You're wired, did you know? Your brain tells your muscles to move by sending them tiny electrical signals. There are strands of conductive tissue between the brain and the muscles, surrounded by insulating tissue to keep those signals from dissipating into the salt water. Pretty much like the insulated wires we deal with as technicians.

When you get connected across a high enough electrical voltage, current flows through and around your muscles and completely swamps the signals from the brain. So your brain tells your muscles to let go, but the signal can't get through, and the muscles stay frozen in place. This is why a shock, which might have been momentary, so often turns into electrocution.

A shock to any part of the body can be damaging, but when people get connected across an electrical potential between their hands, it's especially dangerous. Current flows from one hand to the other, right through the heart. The heart is a muscle. When signals from the brain can't get through, it stops. When it stops, you die.

It gets worse. One type of heart attack is fibrillation, where the heart stops beating and goes into rapid, useless vibration. Power wiring in buildings carries AC, not DC, and in North America it has a frequency of 60Hz (cycles per second). It happens that 60Hz is close to the fibrillation rate of the heart, meaning that an AC shock can easily cause the heart to go into fibrillation. Once it's in that state, it often does not return to regular beating even after the electricity is removed. Thus even a short-term shock can kill if it results in fibrillation.

## OTHER PHYSICAL REACTIONS TO SHOCK

While a continuous shock may prevent muscles from moving, a momentary shock can make them move in a sudden spasm. This can cause you to toss a tool across

the room or drop it into a piece of equipment, creating a far more dangerous situation than existed originally. If your body jerks backward, you can hit your head, and you may knock yourself out and fall into the equipment. It's happened more than once.

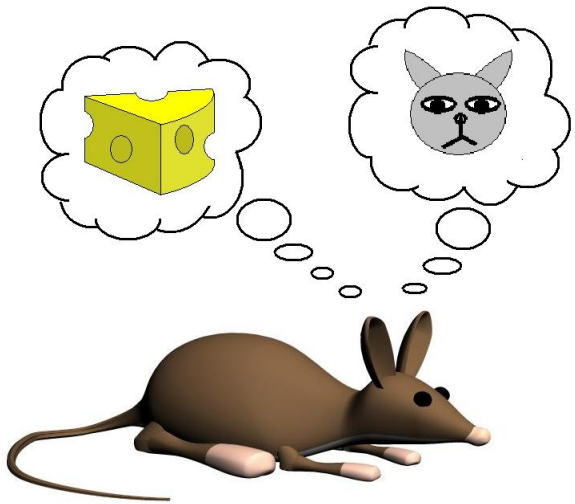
A localized shock can burn skin. Fortunately, this may create a kind of insulation which prevents further shock, but damage can still be severe enough to require emergency treatment.

Electric shock can permanently damage nerves, causing finger numbness or a range of other effects. In fact, electric shock is used to deliberately damage nerves in some cases of severe, chronic pain. There is also some evidence that accidental shock can cause personality changes, which seems plausible when you consider that shocks have been used to treat severe mental illness.

The proper course of action, naturally, is to assume that a shock can always do some kind of damage and take care to avoid it. When it comes to electric shock, an ounce of prevention is worth a ton of cure.

## WHERE ARE THE VOLTS?

When a mouse is looking for food, half of its brain is thinking, “Where's the cheese?” and the other half is



thinking, “Where's the cat?” Likewise, a part of an electronic technician's brain is always thinking, “Where are the volts?” They never forget about that for a moment. When they sense that their attention is wandering, they put down their tools, spend a few minutes doing some other task, and come back when they're ready to focus.

When you encounter a new piece of equipment or arrive on a jobsite, your first task is to make a mental inventory of the electrical (and other) dangers. Only when you are sure you will not be dealing with dangerously high voltages is it safe to relax.

## SAFE AND UNSAFE VOLTAGES

What constitutes a “dangerously high” voltage? Any voltage that's high enough to shock you. There is some difference of opinion about how high this voltage may be. Electrocutions have been recorded with potentials as low as 12 volts, though they are extremely rare.

The following is based on general consensus and the regulations established by the National Electrical Code. A current of 0.01 Amp (ten thousandths of an amp) can be felt as a tingle. If it rises to 0.02 Amp, muscles start to freeze up. 0.1 Amp is fatal. As mentioned in chapter 1, current in a circuit depends on the resistance in that circuit and the voltage across it. The salt water in your body has a fairly low resistance. If electricity can get connected to that salt water, a potential as small as 10 volts can easily produce a current of .01 Amp. But first the electricity has to get past your skin. Fortunately, dry skin has a fairly high resistance.

In the USA, the electrical code considers a voltage safe in dry conditions if it never exceeds 50V, even for a moment. This means the DC limit is 50V. For AC, the safe limit is only 30 volts, because AC has peaks that exceed the average by about 40%, and also because of that fibrillation business. Some other countries are a bit more cautious, setting the DC limit at 30 volts.

If your skin is wet, its resistance is much lower. Accordingly, the U.S. code specifies a 12-volt limit in or around pools, fountains and the like. This does not mean higher voltages are illegal, it means precautions must be taken to keep them away from people.

| SAFE TO HANDLE | | |
|---|---|---|
| **DC** | **AC** | **NEAR WATER** |
| **50V** | **30V** | **12V** |

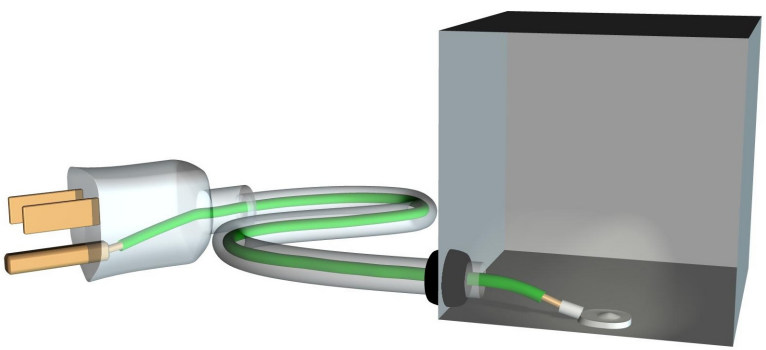
And what it means to you is that you can't fully let down your guard unless there is no voltage anywhere near you that is higher than 50 Volts DC, 30 Volts AC, or 12 Volts in damp or wet conditions. Keep in mind that a situation or piece of equipment that's safe under normal conditions may not be safe when something's broken.

Just because a piece of equipment is powered by a low-voltage source like a 12-volt battery, that doesn't necessarily mean there aren't high voltages present. Some equipment includes circuits called “inverters” that take the low voltage and convert it to a higher voltage. Ya gotta understand what you're working with.

## AC POWER WIRING AND GROUNDS

In 2-wire power circuits, one side of the line is grounded where it enters a building by connecting it to a stake driven into the ground. This wire is called “common” and its insulating jacket is white. The other wire is called “hot” and its insulation is black. In an electrical outlet, one slot is longer than the other, and that's the one that's connected to the common wire.

In newer circuits, an additional green Earth ground wire is provided, which is connected to the round third contact of the outlet. In an appliance or other piece of equipment, this wire is connected to the case or chassis of the unit. The idea is that, if something goes wrong inside the unit and the hot wire comes in contact with the case, the ground wire will short out the current and trip the breaker.



There are other colors of “hot” wire in addition to black. The general rule is as follows:

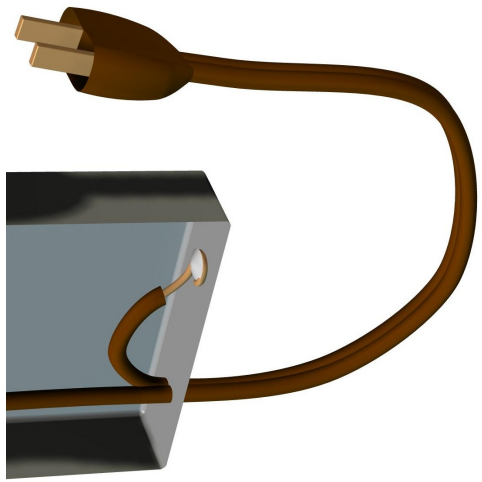
1.White is always common, at or near Earth ground potential.
2.Green is always safety ground, at Earth ground potential.
3.All other colors are hot, at least some of the time.

But don't be too trusting! Electricians, like other people, occasionally come to work with a hangover. They have domestic problems, mortgage payments, and a lot of other things on their minds besides their job. Any experienced field tech can tell you stories from personal experience about the dangerous mistakes electricians often make.

If you find an electrical problem in a building, notify the owner. Tip off: if something you've installed at a particular site keeps burning out and you keep having to replace it, but the same model works fine in other buildings, the cause may be a problem with the electrical wiring. Or, it may be a problem with some other piece of equipment connected to the same AC line. ETA's founder, Dick Glass, once had a problem with an antenna amplifier that kept burning out. The customer lived in a trailer home, and it turned out that the furnace was misconnected, occasionally putting 117 Volts AC on the trailer's metal skin.

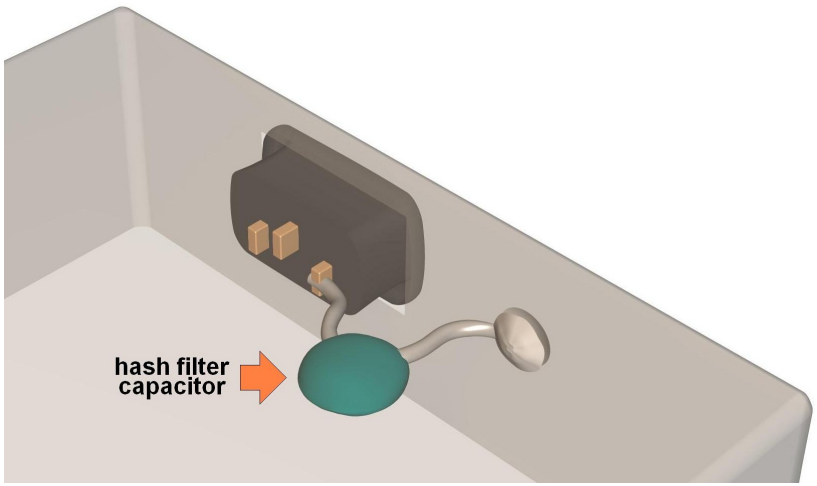
## HOT CHASSIS EQUIPMENT

There was a time when the chassis of a radio or TV was usually connected directly to one side of the power cord. This is called a **hot chassis** unit. From an economy standpoint, there was good reason for doing this. Isolating the chassis from the power line requires a thing called a "transformer," which we will study in EM2, which is often the most expensive part of a piece of equipment. Eliminating it saved a fair amount of dough. But, of course, that made the entire chassis electrically "hot." Not a big danger to the owner if the whole thing was enclosed in a plastic case, but a big danger to anyone who has to take the unit out of its case and work on it. We'll be talking about the workbench isolation transformer a tech uses for protection against this danger.



HOT CHASSIS UNIT

More insidious, perhaps, is the piece of equipment that isn't a hot chassis unit when it's manufactured, but becomes one through failure of a component. There's often a **hash filter** capacitor connected between one side of the power line and the chassis. This is a cheap part that can short out, making the chassis hot.




When servicing a piece of AC-powered equipment, take a meter and check the resistance between each side of the power plug and the chassis. Unless you're working with a unit that's supposed to be hot chassis, you should get an open circuit. If you don't, find out what's wrong before you do anything else.

## STEPS TO AVOID ELECTROCUTION

1. If possible, do not work on equipment while it's connected to the AC power line. Just turning off the switch or pulling a fuse does not make the unit safe. Power line voltage is still present in the circuit before the switch or fuse. Also, if the plug is reversed, the switch can be off and the fuse pulled out, yet the entire circuit can still be “hot.” The only way to remove the risk of electrocution from the power line is to disconnect *all* the wires between the line and the unit you're working on.

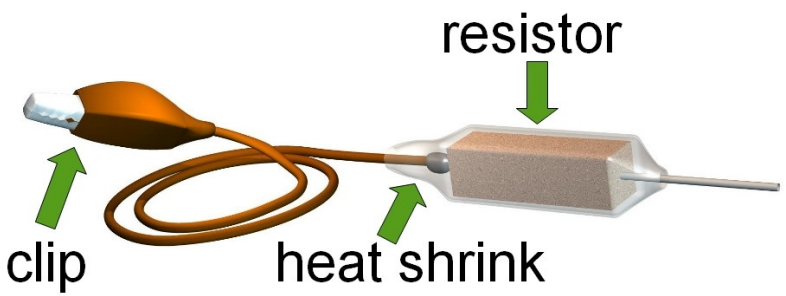
2. When the unit is disconnected from AC power, that means you can't get a shock from the AC power line – but it does not mean the unit is safe! The power supply section in most electronic equipment includes things called **capacitors**, which are energy storage devices. These often store a voltage charge that is *higher* than the AC power voltage, and the charge can last a very long time, even after the unit is unplugged. This is called **phantom voltage**. Also, capacitors usually have very low internal resistance, so they can create a really brutal, high-current discharge.

CAPACITOR

The standard precaution is to take a wire and touch one end to each capacitor terminal while the other end is connected to the electrical common or ground of the unit. Do this only with the main power supply capacitors, not with the other ones you are likely to find throughout the circuit (unless you're working with vacuum tube equipment, in which case discharge all capacitors).

Note that we are *not* talking about discharging to Earth ground – the unit is supposed to be disconnected from all power wiring, right? We are discharging to the unit's own common/ground/chassis.

There's a potential problem. In many of today's complex electronic circuits, a fast capacitor discharge can damage other parts of the circuit. Few things are more embarrassing for a tech than breaking the equipment they're supposed to be fixing. I use a discharging tool that consists of an insulated wire, an alligator clip, a 5-watt, 270-ohm resistor, and some heat-shrink tubing. This takes a little longer to work, as the resistor slows the discharge rate, but it protects all but the most delicate circuits. (Illustration next page)

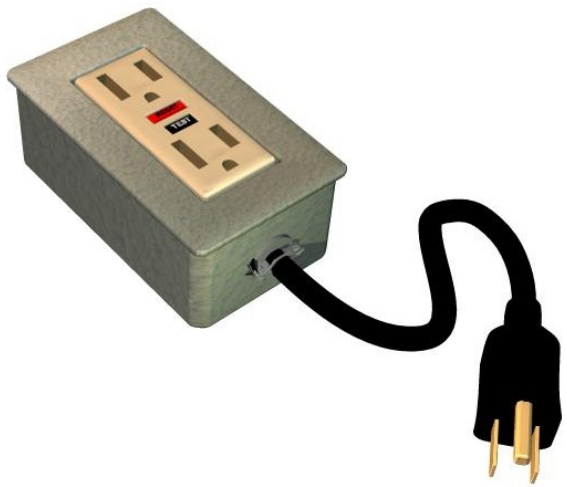


DISCHARGE WIRE

3. With a voltmeter, measure the voltages between a number of points in the circuit and the equipment common. If you find something higher than a few volts, discharge the power supply capacitors again or set the unit aside and wait for the charges to dissipate.

4. If you must work on equipment while it's “live,” establish where the high voltage points are. Unfortunately, they're often right near the main opening into the equipment, and you must reach past them to get at other things. Temporarily insulate these points if you can. Position the equipment so you, or a tool, are not likely to come in contact with them while reaching for something else.

5. Make up an extension cord with a ground-fault-interrupt outlet. Use this to power equipment that you must work on “live.” If you get yourself connected between the AC power and earth ground, the GFI will detect the ground current and shut off. Bear in mind that this will do nothing to protect you if you get connected across a high voltage between two points *inside* a piece of equipment .



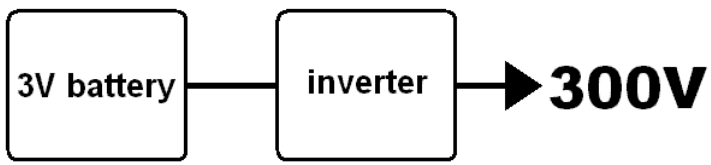
6. Better yet, use an isolation transformer. This is a unit that transfers AC power from the outlet to the unit you want to work on, but separates the circuit from Earth ground. This gives you protection if you get connected between the equipment and Earth ground, which you're likely to do if you're using grounded test gear.

7. When installing new equipment, or working in a new environment, use a tester to check whether the outlet's hot, neutral and ground potentials are as they should be. I once worked on a job where we found the hot wire connected to the ground terminal of the outlet. If any piece of equipment had been plugged into that outlet, its entire case would have been hot - and this was in a room full of other metal-cased equipment that was grounded! If we hadn't found this and fixed it, there is no question someone would eventually have been killed.

8. Never turn off a circuit breaker in an AC breaker panel and assume you're safe. Some doofus is likely to come along and turn the breaker back on while you have your hands inside a piece of gear. If you put tape over the breaker, said doofus will remove it. If you put up a big red sign, doofus will ignore it. This is one case where it pays to have a low opinion of people's intelligence. (Other people's, that is. You, of course, are a genius.)

The only time when you can turn off a breaker, use a meter to verify that the line is dead, and then assume you're safe is when you can see the breaker from your work position. Otherwise, find some other way to disconnect the circuit.

9. Just because a piece of equipment runs on batteries, that doesn't mean it's safe. For example, a xenon photoflash with two 1.5-volt batteries stores a charge at many hundreds of volts. (The squeal you hear is the inverter running.)

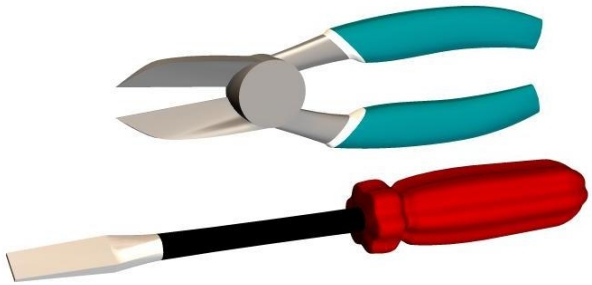



Most video displays are plugged into AC power, but some run on 12 volts. Yet an LCD screen may contain 1,000 volts at startup, and a color cathode-ray tube (CRT) display has at least 25,000 volts inside. Understand the equipment you're working on.

10. Speaking of CRT's, you don't necessarily have to touch a voltage source to get a shock. Very roughly, electricity will jump through one inch of dry air per 10,000 volts. Some CRT displays have more than 25,000 volts inside, which translates to a 2.5-inch jump. And I probably don't have to tell you that a 25,000 volt shock could knock you across the room or worse.

11. Vacuum tubes are not completely obsolete, even today. High-power, high-frequency transmitters still use them, as do microwave ovens, guitar amps and high-test audio equipment. Vacuum tubes always run on dangerously high voltages. If you see them in a piece of equipment, assume that *every* point in the circuit is potentially dangerous. (But then, you shouldn't even start working on any piece of equipment without knowing what voltages you're working with, should you?)

12. Wrap screwdriver shanks in electrical tape or, better, cover them with heat-shrink tubing. Use only pliers and cutters with insulated handles. You might still put a tool across the wrong parts of a circuit and cause fireworks, but the circuit won't include you. The insulation on the tool handles should be appropriate for the voltages you're working with. You never know when you'll have an emergency situation where you have to cut a live wire, and you probably won't have time to put on rubber gloves.



13. Every time you work on a piece of equipment, take a meter and check the resistance from each side of the power plug to chassis ground to be sure the chassis isn't hot. If you don't get an open circuit, find out what's wrong. Also check for frayed cords and replace if necessary.

14. Use the buddy system. Don't work alone. Make sure there's someone nearby who will notice if you're in trouble. Make sure you're in their line of vision, because if you get wired into a circuit the muscles you use to call for help may not work. I almost died once, while a co-worker stood right next to me, facing the other way.

15. I've saved the most important for last. If there's any chance a unit harbors dangerous voltages, work with ***one hand only***. Keep the other hand in your pocket. This has long been regarded as *the* basic rule for working around high voltages. Working with one hand is inconvenient, but it beats getting killed.

## OTHER ELECTRICAL DANGERS

From an electrocution standpoint, the maximum amount of current a power source can deliver is irrelevant. If there aren't at least 50 volts present, you are not in much danger of shock.

But high current can cause other problems. Current flowing through conductors makes them heat up. That's how a space heater makes heat. That's how overloaded wiring burns buildings down.

There is a limit to the current a wire can safely carry, which depends primarily on how thick the wire is. Wire sizes are commonly measured in **gauges**, with *smaller* numbers corresponding to *larger* wires. (Go figure.) In buildings, for example, the rule has long been that 14-gauge wire is rated to handle up to 15 amps, while 12-gauge wire is rated to handle up to 20 amps. Fuses or circuit breakers are provided to open the circuit whenever the current exceeds these limits.

## IMPROPER FUSES

With glass and ceramic cylindrical fuses, and most blade-type automotive fuses, a 30-amp fuse can be inserted as easily as a 1-amp fuse. When the protection device is a fuse, one of the first things a tech must do is check to see that the fuse in the circuit is the right one. The last doofus who worked on the equipment may have put in the wrong size, either from carelessness or because the right size wasn't available.

The importance of a proper-size fuse becomes obvious when you consider that wire heating is proportional not to current, but to the *square* of current, as we will see in chapter 4. For example, if the proper fuse is 5A, but you put in a 6.5A fuse, that permits a 30% rise in current – but the corresponding rise in heating is almost 70%.

Even with a proper fuse, enough current may be available to do serious damage. With cars running on a low 12 volts, high-power circuits require a 30-amp fuse, and 30 amps is serious current. Moreover, “slow-blow” fuses take a while to blow unless the current is far in excess of their rated current.

Bottom line: always replace a blown fuse with the correct size and type.

## CIRCUIT BREAKERS

If you're lucky, the current-limiting device will be a circuit breaker instead of a fuse. It's pretty unusual for the correct breaker to have been replaced with the wrong one, and depending on the type of breaker, it can be very fast-acting. The main danger is that you'll get so tired of the breaker tripping while you're trying to find the real problem that you'll decide to wire around it. Hey, Einstein, if the breaker is tripping, there's something wrong with the circuit, not the breaker! It's *supposed* to trip!

## LACK OF OVERCURRENT PROTECTION

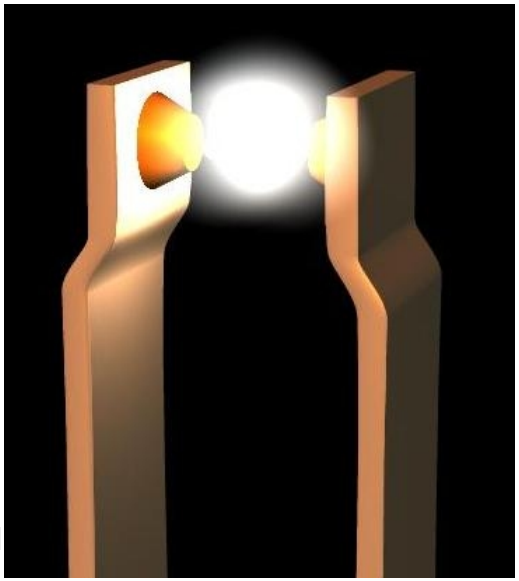
In many cases, there is no fuse or breaker. For example, if you drop a metal tool across the terminals of a car battery, an immense current flow will result. A car battery has very low internal resistance, which it must have to be able to crank the starter on a cold morning.

It is important to understand that concentrated energy in any form – gasoline, dynamite, a strong tensed spring, a brawny battery – poses a danger. And, in an electrical circuit, the lower the voltage, the higher the available current is likely to be. As we saw in chapter 1, and will study further in chapter 4, power is voltage times current. This means that a high-power, low-voltage source must necessarily be a high-current source, and the lower the voltage, the higher the current for a given power level. You can't necessarily let down your guard just because you aren't dealing with a high voltage. An AA-size nickel-cadmium battery can make a wire hot enough to cause burns. So, you may not have to worry about “Where's the volts?” in a low-voltage circuit, but you may need to think, “Where's the amps?”

A specific danger worth mentioning is finger rings. If you're wearing a ring, and it gets connected across a high-current source, you will very quickly come to regret your carelessness. And there's a parallel to the freezing-muscle effect that comes with high voltage: the ring may weld itself into the circuit, so you can't pull it free. The same thing can happen any time an accidental short occurs across a high-current source, turning a minor problem into a major one.

The proper safety measures for high-current situations are the same as for high voltage situations, with one addition: don't wear finger rings. Automotive accessory installers, for example, should remove all hand jewelry. Even the wedding ring has to come off.

## ARCING



When an instantaneous spark turns into a longer-term or continuous one, it's called an **arc**. It does not take a high voltage to cause an arc. Any time you break a circuit where significant current is flowing, an arc occurs unless special steps have been taken to prevent it. If the circuit has been properly designed and the parts properly chosen, the arc only lasts an instant and causes no problems. But where high current is available, if a short circuit occurs and then is broken, a continuous arc can be set up. Once an arc gets started, the air around it ionizes and becomes conductive, and from then on, it is easy for the arc to maintain itself. In fact, this is how old-fashioned spotlights and movie projectors and modern arc headlights work.

An arc can reach an extremely high temperature immediately. That's why they use it to weld metal. Arcs can destroy equipment, set fire to everything around them, and carbonize flesh in an instant.

It is wise to keep a non-conductive tool, like a stick of wood or the insulated handle of a big screwdriver, that can be used to whack arcing conductors apart. You should also be certain there's a fuse or breaker in the circuit, but be aware that once an arc gets started, it does not take especially high current to maintain it. The fuse may not blow.

## FUSED SWITCH CONTACTS

Speaking of “whacking apart” - if a switch or relay has not been properly sized to handle the normal arcing that may occur, the contacts may weld together, resulting in a permanent closed circuit and a machine that won't shut off. This can quickly result in an emergency. Actions to take:

1. Push anyone who is in harm's way out of danger.
2. Grab any tool with an insulated handle and whack the relay or switch – hard. Don't worry about cracking the case. Buying a new switch is the least of the problems you could have.
3. Many relays are plug-in units. Unplugging the relay will break the circuit.
4. Grab a pair of wire cutters with an insulated handle (you should not have any other kind in your tool kit) and cut the main power wire. If you're dealing with large machinery, don't be surprised if cutting the first wire doesn't stop the machine. Big motors usually run on 3-phase power, and may not stop when the first wire is cut. You may have to cut two or three. Cut single wires only – DO NOT cut a cable that has several hot wires or a hot wire and common! Once you've cut a wire, the exposed end poses a danger, so you're not finished dealing with the emergency until you've taped or capped the bare ends.
5. As always, prevention is best. One of the first things you should do when you arrive on the job site is identify a point “upstream” (earlier in the circuit from the unit you're working on) where power can be switched off.

## IMPROPER PARTS

Some parts of some circuits must be replaced only with exactly identical parts, or a fire or other problems may result. These will be indicated on the schematic diagram by shaded areas or other notations.

## INDIRECT DANGERS

There are dangers that do not directly involve electricity, but which are created by electric equipment.

**X-rays:** Some equipment is designed to create x-rays; in other cases, x-rays are created by malfunction. One example is a malfunctioning CRT display. Under normal conditions, weak x-rays are generated which are adequately contained by the glass tube. However, a malfunctioning display may create x-rays which penetrate the face of the tube. As a general precaution, when a CRT display is malfunctioning, stay away from the front of the tube.

**Microwaves:** There's a good reason a microwave oven includes an interlock that prevents it from running when the door's open. The purpose of a microwave oven is to cook things like meat. You are meat. Needless (I hope) to say, never defeat this interlock. Also, if you're working on a microwave unit, check to be sure the energy-containing gasketing is in place and undamaged.

If you work with microwave-transmitting communication devices, avoid being exposed to radiation. Fortunately, the radiation of high-power microwave units is usually confined in a narrow pattern, so you only have to stay out of its path. Be aware, though, that a reflective object placed in the radiation path can redirect it. Microwave *receiving* devices, on the other hand, generally pose no danger.

Microwaves can't be seen, heard, smelled, tasted or felt, so a lot of damage to your innards can occur before you're aware of it. Sometimes, the fact that a person has been exposed to strong microwaves is only discovered in the emergency room. Anyone who works with microwaves should carry a microwave signal detector. Use the detector to thoroughly sniff out the job site before you start working, and develop the habit of visualizing the signals you discover.

One of ETA's newest certifications is for **PIM testing**. PIM stands for **Passive Intermodulation**, and it's what happens when an antenna distorts the signal fed to it by a transmitter. PIM testing occurs at high power levels and it's very dangerous unless you've received special training for it.

**Ultraviolet Light:** some equipment makes very strong ultraviolet light, which can cause skin redness and damage your eyesight. Again, this equipment is supposed to be labeled, but it isn't always. Far ultraviolet is most damaging, and it's completely invisible.

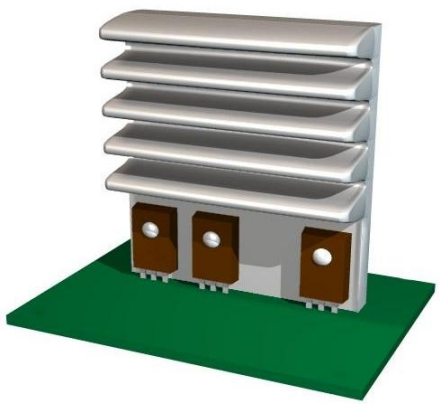
**Ozone:** High voltage discharge causes ionization of the air. Ionized air is ozone. Ozone is a poison. A weak concentration of ozone can be beneficial, as it poisons germs without hurting people. The clean aroma of a clear, sunny day is ozone. That's why fresh air is recommended for people with respiratory infections. But in large doses, it can damage your throat, lungs and nose tissues. If you get a strong whiff of it, turn off the equipment, clear the area, and ventilate. Also, do a quick mental check: is there *supposed* to be a voltage present that's high enough, or x-ray or ultraviolet radiation strong enough, to ionize air? The sudden smell of ozone may be a tip-off that something's gone seriously wrong and you better shut off the equipment and get the heck out of there.

Some equipment generates ozone in normal operation. This equipment is supposed to carry warning signs.

## OTHER WORKPLACE HAZARDS

Naturally, a tech can slip and fall, be stabbed by a sharp object, or suffer any of the accidents that any worker might experience. However, there are some risks which are not directly related to electricity, but do apply especially to electronic techs.

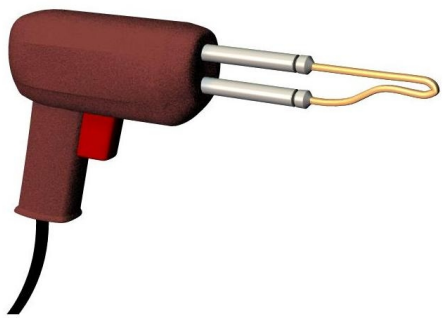
**Burn hazards:** A lot of electronic equipment generates high temperatures, either on purpose, as part of its normal function, or as an unavoidable byproduct of it. And equipment that doesn't normally get hot may do so when it's malfunctioning. If you see something glowing red hot, that means it's at least 1,000 degrees Fahrenheit. Internal parts of vacuum tubes, including CRTs, are one obvious example. A lot of the heat generated inside the tube transfers to the envelope, and of course, if the tube breaks, you are directly exposed to both red-hot metal and high voltage. Fortunately, many high-power tubes have metal and ceramic cases, so they're hard to break – but they're still hot.



A surface does not have to get red hot to produce a burn. Prolonged contact with a surface that's at 160 degrees Fahrenheit, which is the temperature of very hot coffee, can do it. You should check out where the hot spots are when you begin working on a unit. A heat sink should be assumed to be hot until you find otherwise. There will not necessarily be any visual cue to tip you off other than the fact that it is, after all, a heat sink.

As a tech, you are likely to use a soldering iron so often that it almost becomes an extension of your arm. To melt solder, the iron typically operates at 700 degrees, often higher with today's lead-free solder. You need to develop good workbench techniques so you don't burn yourself with the iron or the little drops of molten solder that fall off the iron if you don't clean it as often as you should. Wherever you take the iron, take a holder so you won't have to set the iron down on a surface. It doesn't necessarily have to touch something to cause a problem; a soldering iron is hot enough to melt things or set them on fire by radiation.

Make sure the cord is long enough and there's nothing it can get snagged on. Otherwise, when you reach out, the iron will be yanked back and you will find yourself with a flesh-searing piece of metal between your fingers.



Consider using a soldering gun on the job site. This is a crude tool nobody likes. An expert engineer of my acquaintance, when he sees someone using a gun, automatically assumes the person is incompetent. Nevertheless, a gun has one great advantage: ten seconds after you release the trigger and put it down, it's no longer hot enough to burn a hole in the carpet. Unfortunately, a gun is too clumsy for fine, delicate work.

You will no doubt be using plastic heat shrink tubing, and shrinking it with a hot-air gun. A heat-shrink gun is not to be confused with a hairdryer! At its highest setting, its air stream can melt solder. This makes it more dangerous, perhaps, than a soldering iron because you can get burned without touching it, because it can set things on fire at a distance, and because its danger isn't as obvious.

Another non-obvious danger: have you ever been burned by hot-melt glue? I know this isn't strictly electronic, but a lot of techs use glue guns. I'm thinking of this because I just burned myself before sitting down to write. What makes hot-melt glue especially nasty is that it sticks really well to skin. (It's glue, after all.) That gives the stuff a lot of time to do damage before it cools down.

**Fire:** If you're using a soldering iron, you are always in danger of setting the place on fire. The best preventive is to remove as much flammable material as possible from the workbench and the area around it.

*Never* shake molten solder off an iron into a wastebasket! Molten solder is easily 200 degrees hotter than the temperature needed to set waste paper on fire. Paper can smolder all day, then flare up at night and burn the building down.

Store chemicals and rags away from the bench, ideally in a metal cabinet rated for the purpose. Before you bring them to the bench, move the hot soldering iron far away. Some years ago, a prominent electronic parts distributor in Minneapolis burned to the ground when an open can of solvent was tipped over onto a hot soldering iron.

Solvents become much safer when they're contained in a push-top dispenser. This kind of container has a valve which dispenses a measured amount of solvent into a rag when pushed. The solvent-soaked rag can still catch fire, but the largest part of the solvent, contained inside the reservoir, cannot. Employers and government regulations often mandate the use of these dispensers.

On your workbench, you should have one large switch which immediately disconnects all power. This is useful in an emergency, and also to give you peace of mind: turn it off when you leave the work area, and you can be confident you haven't accidentally left a hotplate or hot soldering iron running.

Keep the work area neat, and clear it when you're done with a task. Keep solvent bottles capped and away from the immediate work area. Don't smoke in the work area, not just for safety reasons, but also because it's unprofessional.

Finally, keep a fire extinguisher of the proper type (see below) nearby.

**Chemicals:** Many chemicals are dangerous to breathe, or to get on your skin.

The fumes from soldering are damaging if you inhale a lot of them, which you will do if you don't take precautions. A soldering iron is normally held at a downward angle, and the heated air movement causes smoke to travel along the iron and then rise directly into your nostrils, as if it were possessed by an evil spirit trying to poison you.

The best solution is forced-air ventilation to the outside. Where this is impractical, use a small fan with a filter that traps the smoke. These are available from the people who make soldering irons.

Solvents and other chemicals are likewise dangerous. They damage by stealth; you often aren't aware there's a problem until it's many years too late. Always work in an area that's ventilated to the outside if you can. Some chemicals can enter your body through the skin; there should be a warning on the bottle. Note that there are usually several chemicals available for a particular job; those that pose the least risk will be advertised as such.

## DAMAGE TO VISION

Whenever there is the slightest chance something could fly into your eye, wear eye protection. If you can't stand goggles, get safety glasses. Even if you only require a trip to the doctor to get a piece of crud removed, that'll cost you more than the glasses would have.

Did you ever burn up ants using a lens to focus sunlight on them? Of course you didn't, you were a saint, it was those other little brats. Um, right. Anyway, the lens in your eye can do the same thing to your retina. You already know better than to look at the sun, but you should treat any bright light source with similar respect. Even if it doesn't ruin your retina, a bright light can damage it to the point where your vision starts to deteriorate at too young an age. Lasers are especially dangerous. Kids can buy them, but that doesn't mean they're safe. Maybe kids shouldn't be able to. Even light-emitting diodes are getting bright enough to be dangerous.

The most dangerous light is invisible light, because you don't know it's present until too late. Ultraviolet light has already been mentioned, but nowadays there's something even more dangerous: the infrared light used in fiber optics. It's often produced by lasers, it's very concentrated, it's often almost as strong coming out of an optical fiber as it was when it went in, and you can't see it. However, you certainly can see the black stripe that results when you move a live fiber across your field of vision. That's a burn on your retina, and you will see it for the rest of your life.

Not all fiber optics are this dangerous. Short links often use visible light, or infrared light of lower intensity. Naturally, you should know what you're working with. And when there are lasers around, you should wear laser-appropriate safety glasses *at all times*. If you need to take them off, leave the work area first.

Like electrocution, laser damage to vision is usually instantaneous, always unexpected, and permanent.

Anyone who works with fiber optics should keep a light detector handy. This is a card that converts infrared light to visible, so you can see it. But don't ever trust a laser to be off. It might come on while you're looking at it.

Losing an eye is like getting wired into a high-voltage circuit: after you say “oops,” there's nothing you can do. Someday it may be possible to replace eyes, but I wouldn't bet my future on it. The retina is an extension of the brain. Science-fiction stories notwithstanding, nobody really knows how the brain works or has a clue how to make a replacement part.

Naturally, you also wear goggles when there's a chance something could fly into your eye, like when you're using a grinder. Is it likely to happen? No. If it does happen, could you be blinded for life? Yes. Eventually everyone learns – sometimes the hard way – that you have to pay attention not only to the odds, but to the consequences.

Once in a while, examine your goggles. Over time, the plastic lenses fog up or start to go opaque. Resistance to scratching decreases. The lenses become brittle and more easily shattered. Goggles aren't expensive, there's no reason to use old ones after they become unsafe.

## HEARING DAMAGE

Of the five senses, hearing is the only one where you don't necessarily have any warning while damage is happening. Bright light hurts the eyes; a cut or abrasion hurts the skin; caustic fumes sting the nose. But the hearing mechanism consists of delicate nerve endings that can break off without any pain or strange feeling. Except in extreme cases, the damage can go on for years before you notice. Eventually, you find that you can't understand speech, music is noise, loud sounds cause disorientation, a quiet environment drives you nuts because your ears are whistling, and young people make fun of you behind your back. By then it is decades too late to do anything about it. It's ironic that those whose whole lives revolve around hearing – musicians, record producers, sound system techs – are often those who damage their ears earliest and have to leave everything they love behind long before they get old. I understand the adrenalin rush from standing right in front of the speakers at a rock concert, but the eventual cost is too high. I'm sixty now, and many of my Led-Zeppelin era friends can't stand to listen to music at all; it's just noise to them. Meanwhile, I'm still living my other life as a professional musician, and my hearing probably works better than yours. That's because I've been careful.

It takes surprisingly little noise to damage your hearing, especially if it's sustained for a long time. If you find your hearing is a little off after you've been in a noisy environment for a while, you can be sure permanent damage has been done. Your hearing will probably return to normal now, but in years to come, the damage will show up.

If it's stupid to trade enjoyment of loud music now for hearing problems later, it's even more stupid to permit your ears to be damaged by sounds you don't enjoy – saws, hammers, alarms and so on. There's a certain macho flash to working in a noisy environment without ear protection, but you'll pay for it.

The hearing mechanism, like the seeing mechanism, is an extension of the brain (there's a reason four of the five senses are in your head) and it's unrepairable.

Rule of thumb: if a sound is annoying, it's likely dangerous. Treat your ears as the fragile things they are. Get earplugs, they're cheap. Others may make fun of you, but you will have the last laugh when you're all middle-aged and they're deaf. And there's one person who won't make fun of you: your employer. Accidents and injuries cost employers a fortune. If you take reasonable, quick, cheap steps to protect yourself, they'll approve. They may even view you as potential management material.

If your co-workers laugh, tell them your hearing is important to you because you're deeply into 17th-century opera. Then they'll *really* laugh.

## CLOTHING ISSUES

I wish I could skip over this one, it turns my stomach. As I began to write this chapter, in April 2011, there was a story on the news about a 22-year old Yale student who was killed when her hair got caught in a lathe. If you must wear long hair, tie it up or wear a hair net while working around machinery. It looks bad, you say? Not as bad as...I'll leave it to your imagination.

Ties, neckwear etc: never wear a hand-knotted tie around rotating machinery; only wear the clip-on type. If it gets caught in the machine, it will likely be snatched off rather than pulling you into the machine with it. Wear a reliable tie clip. Tight clothing is better than loose, and short-sleeve shirts are better than long.

Finger rings: don't wear them, especially when there's a high-current power source present. This caution should perhaps be extended to all kinds of body jewelry. A dangling metal necklace could electrocute you.

Shoes: if you work in an environment where there's any chance your toes could be crushed by something heavy, wear steel-toed shoes.  Your employer may require it, and may reimburse you.

## MISCELLANEOUS SAFETY ISSUES

It's useful to have a supply of paper tags with string – bright orange are best, if you can find them.  These can be used to identify danger points and make other kinds of notes.

Also, it's useful to keep a supply of general-purpose danger signs, as well as blank orange paper and felt-tip marker so you can make your own.  If you have them on hand, you'll be more likely to use them.  Remember, it's just as important to not hurt other people as to not hurt yourself.

## GUM

Am I really going to tell you not to chew on the job?  Wow, I'm turning into your mom.  But if you should get a shock, and be knocked unconscious, that gum will block your airway.  Okay, tell me I worry too much.  It's your funeral.

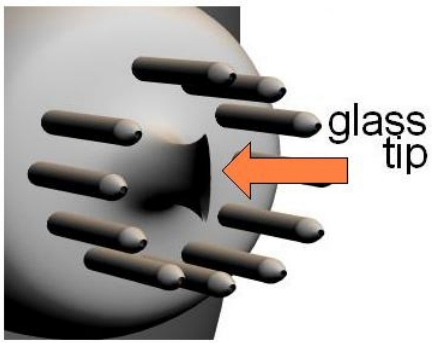
DEALING WITH CRT'S

Cathode ray tube (**CRT**) displays are all but obsolete in the computer field, but that doesn't mean you'll never have to work on them.  Old ones are still in use, and  Wal-Mart was still selling new CRT TV's in the fall of 2010.  Many of those will still be in use in 2025.

A CRT is a big glass tube with a high vacuum inside.  If the tube breaks, it implodes, which is the opposite of explosion. Glass shards are sucked into the center at high velocity, and many of them fly past each other and right back out again. In other words, the net effect is the same as explosion.

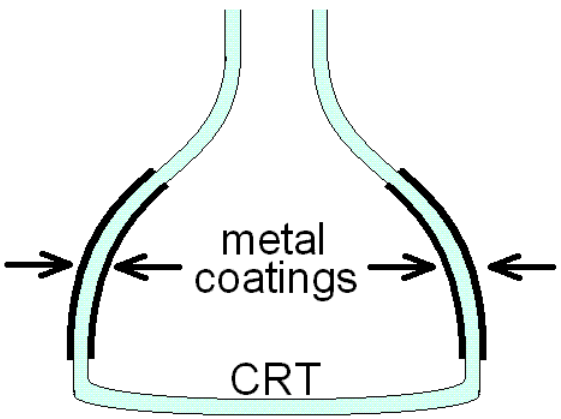
As long as the tube is installed in the display enclosure, it's pretty safe.  The only part that's exposed is the face, which is strongly reinforced.  It takes something like a bullet to shatter a CRT face.  But the rest of the tube is a lot less sturdy.  The weakest part is the neck, which can break off and start an implosion.

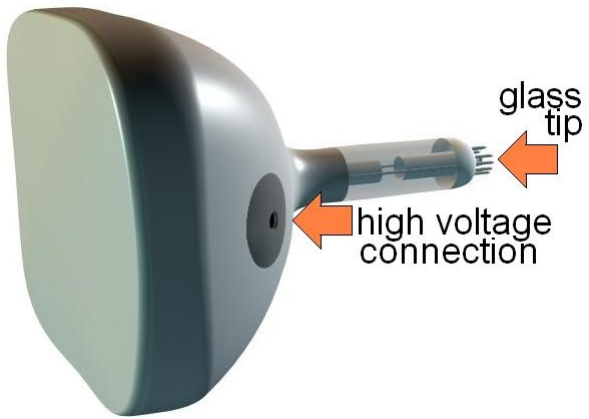
When an old CRT is being disposed of, a responsible tech will relieve the vacuum by breaking off the little glass tip at the very back of the neck. This should be done with the whole tube placed in a cardboard box, in case it does shatter.




A CRT involves one other great risk. The inner and outer surfaces of the tube are coated in aluminum. These two surfaces, along with the glass between them, form a big Leyden jar, which is another name for a capacitor. This is where the 25,000 (or more) volt charge is stored.
When the CRT is connected into the monitor; the outer coating is at ground and the inner coating is at +25,000 volts.

In most cases the inner coating is connected to a round terminal in the side of the tube, and this gets attached to a connector that looks like a suction cup. There are two fingers under the suction cup that catch inside the rim of the terminal on the tube, like the wires that hold a Christmas tree ornament from the inside.




If you're working on a CRT monitor, take the clip end of that discharging tool you built and attach it to the metal chassis. Take the other end and poke around under the connector until you make contact with the fingers. This will discharge the high voltage.

## YOUR VEHICLE

If you work in the field, pay attention to the condition of your truck. If it breaks down at a customer's site, or on the way to or from, you and your company will look like a bunch of clowns, and of course some breakdowns can lead to injuries.

If you keep a ladder tied to the top of your truck, secure it so it won't break loose and become a torpedo, even in the event of a collision.

On the road: do you really have to use that cellphone while driving? Yes, you want to save time and optimize your route, and things come up unexpectedly. But it seldom takes longer than three minutes to find an exit and pull over. Do you really love your boss so much that you can't wait three minutes to talk to him or her? If you must phone while driving, it's worth the trouble to set up the cellphone so you can use it completely hands-free.

I know what you're going to say: “I don't call the office on the road, but they call me – what if I don't answer, and then when I call back, I'm 30 miles from where I should be?” A lot of that can be avoided by being proactive. Call in before you leave the jobsite. And, while you've got the phone in your hand, take a minute to record – or write down – details of the job such as extra work you want to remember to charge for, and who authorized it.

Texting while driving: this is so stupid I can't even find words to describe it. If your aim is to save time, why would you text when talking is at least three times faster? As bad as phoning while driving is, it's much less dangerous than texting. The upside to texting is, maybe you save a few minutes, but probably not. The downside is that you die and kill other people. It probably wouldn't be any more dangerous to drive drunk.

When you're driving, your job is to drive. Give it your full attention. You heard it from your driving instructor, you heard it from your parents, and if you're careless, you'll hear it from a judge. I hope you don't hear it from a lawyer representing the family of somebody you killed.

Residential installers should keep dog repellent and hornet spray in the truck. Keep several pairs of work gloves if your job gives you any reason to. The more protective they are, the clumsier, so you should have several kinds on hand and use the right ones for each job.

## FIRST-AID KIT

Keep a first-aid kit in the shop and another in the truck. This does not have to be elaborate. Serious injuries will require the intervention of medical personnel; the purpose of a first-aid kit is to treat minor injuries so they don't get worse, and so you can get back to work. A basic kit with bandages, sterile gauze, tape and scissors, topical antiseptic/pain killer and oral pain killer will be adequate. If anyone in the crew is diabetic or has a serous allergy, the kit should include appropriate medications. The most important thing is, keep it stocked. Don't use up the stuff and be caught without it when you need it. If you're in a shop with a number of employees, decide on somebody specific whose responsibility it is to keep the first aid kits stocked.

That pretty well covers the basics of prevention. But what do you do when something bad does happen?

## FIRES

We're going to look at different types of fire extinguishers, but first we must address a more important question: should you even try to put a fire out? Many people have died because they tried to extinguish a fire instead of getting out of the building.

Most people have no clue how fast a fire can spread. Things can progress from a small fire to a room full of smoke to a flaming hell in fifteen seconds. Smoke is often flammable. Take a look at a photo of a burning building; you'll see that the very air is on fire. Smoke can also be so acrid that a single lungful will kill you.

Better to lose a building than the people in it. If a fire starts, you should get yourself and everybody else out of the building as fast as possible unless you are certain that the fire is small and contained and you can easily extinguish it.

## FIRE EXTINGUISHERS

Fires are divided into four categories:

Class A: combustible materials like wood and paper
Class B: flammable liquids like grease and solvents
Class C: electrical fires
Class D: chemical fires

The proper type of extinguisher is, of course, one designed to handle **Class C fires**. There are two general types: dry chemical and carbon dioxide or $CO_2$. A dry chemical extinguisher works best, but leaves a residue which may be corrosive. Once the fire is out, you have a cleanup task ahead of you. A $CO_2$ extinguisher leaves no residue to clean up, but you have to be sure the fire is really out, because a $CO_2$ extinguisher gives no protection against re-ignition. The dry extinguisher's chemical residue, on the other hand, acts as a non-flammable coating and helps keep the fire out.

*Never* try to put out an electrical or solvent fire with a water-based (Class A) extinguisher. If it's an electrical fire, you can be electrocuted. If it's a solvent or grease fire, the water will splatter the burning material and make the fire worse. In fact, there shouldn't be a Class A extinguisher anywhere around an electronic workbench.

## TREATMENT FOR ELECTRIC SHOCK

The first thing to do, of course, is to disconnect the source of electricity, or disconnect the victim.

If you're assisting someone else, the important thing is not to become part of the electric circuit yourself. One victim is bad enough. Remember that wooden stick? If it's handy, use it to move the wire or the person. Or grab any insulating object, like the handle of a tool. If you have rubber-soled shoes, you can kick. Or you may be able to use the metal part of a tool to short the wire to a good ground, which will trip the breaker.

**Mouth-to-mouth:** if the victim is unconscious and not breathing, perform mouth-to-mouth resuscitation. Lay the victim on their back and lift at the back of the neck, so their head tilts up. Clear the airway with your finger if necessary. Take a full breath and transfer it into the victim's lungs. 12-18 breaths a minute (every 4-6 seconds) are appropriate. You'll have to pinch the victim's nose or block it with your cheek so the air doesn't escape.

**CPR** (cardio-pulmonary resuscitation): this is something you should perform only if you're trained; otherwise you can make a bad situation worse. Speaking of CPR training, why not go ahead and get some? Many communities offer it for free. Once you've got it, put it on your resume. There's a lot of competition for good jobs these days. CPR training could be your ace.

## CHOKING

While getting your CPR training, learn the Heimlich maneuver. Put that on your resume too.

## CUTS

Wash clean, compress until bleeding stops, apply a topical antiseptic, and bandage. If the cut is large or deep enough that it will tend to come open, or if it's on a joint that flexes, get stitches.

## BURNS

Burns are divided into three classes:

1. First degree: a minor burn, the thin outermost layer of skin is burned. Skin is red with swelling and some pain.

2. Second degree: the outermost layer is burned through and the second layer is burned. Skin is splotchy red with severe swelling and blisters. This requires medical attention, but is not an emergency unless the burned area is larger than 3 inches in diameter.

3. Third degree: skin is burned black or may appear dry and white. Skin is burned through and underlying fat, muscle and perhaps bone is involved. This is an emergency requiring immediate professional attention, even if the affected area is small.

Treatment for minor burns: First, cool the burn. Hold it under running cool (not cold) water for 10-15 minutes, or if that is impractical, immerse it in cool water. Second, apply sterile gauze to protect the area and keep air away. Wrap the gauze loosely and tape it. Do not use cotton or any material where fibers could get stuck to the wound. Third, take an oral painkiller.

Do not apply ice, which can cause more damage. Do not apply butter or ointment, or break blisters, which can cause infection. A minor burn will usually heal without medical attention, but if signs of infection develop, see a doctor.

Even minor burns require medical attention if they occur on large areas of hands or feet, or in groin or buttock area, or over a joint such as a knee.

As a follow-up, get a tetanus shot. Doctors recommend getting one every ten years anyway, but after a burn, a person is more susceptible to infection.

Treatment for major burns: First, make sure the victim is not still in contact with smoldering material or exposed to smoke or heat. Second, call 911. Third, while still on the phone, check for movement or signs of breathing. If none are present, begin emergency resuscitation. If it is likely that the victim is suffering from smoke inhalation or carbon monoxide poisoning, tell the emergency operator. Fourth, if it can be done without causing more damage, elevate burned parts, preferably above the heart. Fifth, loosely cover the burn with a clean moist cloth or gauze.

Do not remove clothing unless it is still smoldering. Do not immerse severely burned tissue in cold water. Anything you put on it makes it harder for the medics to deal with.

## SAFETY CODES

The “gold standard” of electrical safety codes is the **National Electrical Code** or **NEC**, a big fat book published by the National Fire Protection Association. If I were to excerpt even the most relevant parts, it would double the size of this study guide, and there's little point since you can get a copy of the NEC and study it yourself. Anyone who seriously intends to work outside a shop will eventually have to take a class or two in the NEC. Many states require technicians to take code classes every few years to maintain their licenses.

The NFPA is not a government agency and NEC code is not law. However, every government jurisdiction bases its electrical codes on the NEC. Some jurisdictions adopt the NEC lock, stock and barrel, while other jurisdictions are less strict or more strict. It is up to the technician to know the codes in a particular area. The most practical way to do that is to learn the NEC code, then learn the variations in your locality. That way, you can work anywhere in the USA with only minimal re-learning. If you don't want to buy the book, borrow it from a library and spend half an hour a day for a couple of weeks looking through it. Take notes.

## HAZARDOUS MATERIAL DISPOSAL

As electronic techs, we often work with materials that should not be simply thrown in a dumpster. This problem is being reduced as manufacturers switch to environmentally friendly materials, but hazardous material that's already in existing products will be around for a long time, so we have to be aware of what we're doing.

In the USA, most techs are still using tin-lead solder.  I have a metal can by my bench where all solder blobs go as well as any old parts removed from equipment, which still have tin-lead solder on their terminals.

CRT displays have lead in their glass and their phosphors often contain cadmium, which is very poisonous to humans.

Speaking of cadmium, nickel-cadmium batteries do, of course, contain considerable amounts of cadmium.

Wherever you live and work, find out about the approved hazardous material disposal sites and procedures.  Even if you're not personally inclined to take this seriously, improperly disposed material is a legal time bomb; you are liable for it far into the future.

***End of chapter 2***

# EM1 Chapter 3
# DC CIRCUIT MATH

**by Karl Eilers**

*Objectives covered in this chapter:*

- *Describe the basic functions of a scientific calculator.*
- *Explain basic algebraic math and its application in DC electronics.*
- *Identify the scientific symbols used in DC electronics.*
- *Explain how to convert fixed numbers to scientific notation and engineering notation.*
- *Identify the base units of the International System of Units (SI).*
- *Describe the SI names and symbols that apply to electronics.*
- *Describe standard metric conversions.*
- *Explain algebraic equations relevant to DC circuitry.*

If you want to do electronics, you have to do math – not the advanced, complicated stuff, but you need to know the basics and know them well.

This chapter is written for those who have always struggled with math, on the assumption that adult students who are naturally good at math will already know most of the material. I'm pretty sure you half-know a lot of this already, so you'll probably be able to just skim over a lot of it.

This is a big chapter, don't try to swallow it all at once. We're going to cover a lot of ground – I figured, since a big download doesn't cost any more than a small one, might as well give you good bang for your buck. The best way to do this chapter is a bit at a time. If some of the material is new to you, you won't get it all on the first reading. Don't worry about that. Go thru it until you reach a point where you're not picking it up easily. Make a note of where you are, then go on to the next chapter and come back to this one when your mind has rested a bit. I'm going to assume you already know about addition, subtraction, multiplication and division, and pick it up from there. If you're a little shaky on those things, there's lots of practice material available on the web for free. But even if that's the case, don't wait to get started. You can lean on the calculator to help you through the exercises for a while.

The most important thing is mindset. You should confidently expect this stuff to make sense. Of all the sciences, math is the most faultlessly logical and the most precise. And, despite what they tell you, basic math isn't abstract; it's as mechanical as hammers and saws. In fact, you're probably going to find some of this an insult to your intelligence.

## STANDARD AND SCIENTIFIC CALCULATORS

Speaking of calculators, you should have one at hand whenever you're working with these study guides. Calculators can be divided into two groups, "standard" and "scientific." A standard calculator has at least the four basic arithmetic functions of addition, subtraction, multiplication and division, plus (usually) a square root function. There's also a M+ key, which allows you to add a number to memory, keeping a running total, a MR key, which allows you to fetch the number that's in the memory so you can work with it, and a MC or memory clear key to reset the value in memory to zero.

To these standard functions, a scientific calculator adds reciprocal (1/x), square( $x^2$), square roots ($\sqrt{}$ ) , exponential powers of ten, logarithmic (log), trigonometric (sine, cosine, tangent etc) and other functions.

"Graphing" scientific calculators can draw pictures of math functions. Scientific or exponential notation functions are easily performed with the EXP or EE key to work with large and small quantities, or when converting units from one metric unit value to another. The exponential value is displayed to the right of the numeric value on the screen, sometimes separated by a space. The INV or Inverse key can be used to change the exponential value back to basic units. Most scientific calculators have two or three functions assigned to each key, so make sure that you are using the correct mode.

Calculators differ so much that it would be pointless to try to describe all the functions here. Consult your user's manual; scientific calculators in particular come with very detailed instructions.

For the math in this study guide, a standard calculator that handles square roots is adequate. Beginning with EM2, you'll need a scientific calculator. If you get one that handles octal and hexadecimal conversions, that'll help you in EM4. Scientific calculators can be bought for $15, so there's no reason not to get one; it's one of the most powerful tools you'll ever own.

Spend some time with the user's manual becoming familiar with all its functions. Put the manual in a safe place; as your understanding of math increases, you'll be in a position to go back and learn how to use more of the calculator's functions.

In the meantime, there's probably a calculator on your computer. If you're also reading this study guide on the computer, adjust the windows so you can have the calculator and the study guide on screen at the same time.

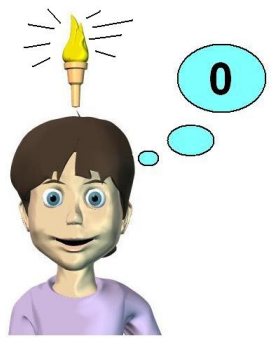
## WHOLE NUMBERS

You're no stranger to numbers, you've used them all your life, but we need to take a closer look. The number system we use is called the **decimal** system because it's based on the concept of ten numbers, 0 through 9.
In large numbers like 123,456 each of the individual numbers is a **digit**. Each digit occupies a specific place. With whole numbers, we always know that the digit farthest to the right is the "ones" place, representing quantities from 1 through 9. Then, as we move to the left, each digit signifies ten times the value of the one to its right. Place values for the number "123,456" are as follows:

| 100,000 | 10,000 | 1,000 | 100 | 10 | 1 |
|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** |

We can continue to the left as far as needed to write a number of any size, no matter how large.

Since the significance of a digit depends on its position, a number like "one thousand" presents a problem. If there are no hundreds, tens or ones, we won't have any numbers to write in those places, but we still need to indicate that the "1" is four places to the left. So we write zeroes in those places to "hold" them. Zeroes used in this way are called **place holders**.
It may be hard to believe, but people only thought of numbers as signifying things for thousands of years before it occurred to some smart person to create a number to signify a lack of things. The concept of "zero" was one of the most significant advances in the history of mathematics.



The kinds of numbers we've been talking about are called **whole numbers** or **integers** (IN-ti-jurz) because they have no partial quantities; they represent whole, complete things. The smallest quantity that can be represented in whole numbers is 1.

## FRACTIONAL NUMBERS

A fraction indicates a quantity that falls between integers. A **common fraction** is written with one number over another, as in

$$\frac{3}{4}$$

...or, in a line of text, written with a slash, as in ¾. The lower number is called the **denominator** and it tells us how many pieces something is divided into. The upper number is called the **numerator** and it tells us how many of those pieces we actually have. For example, if we cut a pie into 5 pieces, then we'll have $^5/_5$. If we eat two, we'll be left with $^3/_5$.

In a **proper common fraction**, the numerator is less than the denominator, meaning that the quantity is less than 1. It's possible for a common fraction to be greater than one – for example, if we have $^3/_5$ of a pie and another whole one, then we have $^8/_5$ total. This is an **improper common fraction**. In such cases it is customary to convert the quantity to a **mixed number** consisting of an integer with a fraction following, e.g. $^8/_5$ becomes $1^3/_5$.

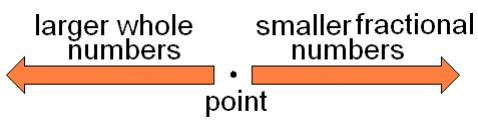
On the other hand, when we're doing calculations, it's often necessary to go the other way, elimintating the integer and leaving us with a fraction greater than one which we can use for number crunching.

As logical as common fractions are, they aren't the best for doing calculations, especially with a calculator. Later on, I'm going to show you how to add and multiply fractions. As you'll see, dealing with simple decimal numbers is a lot easier. So, where it's possible to do so, most engineers and techs prefer to work with decimal fractions.

A **decimal fraction** is a fraction that is written out in decimal form. We know that, in a whole number, the right-hand digit represents the "ones" place, and each place to the left represents a quantity that is ten times the one to its right. The farther we go to the left, the larger the quantity.

But we can also go to the right. What would that mean? Well, each place to the left of the "ones" place is larger by ten times – tens, hundreds, thousands. That would imply that each place to the right is *smaller* by ten times – tenths, hundredths, thousandths. If we want to write down quantities that are smaller than one – for example, if we're dealing with an electrical current smaller than one amp, which is the usual case in electronics – we put those numbers to the right of the "ones" place.

Now that we're going both left and right from the "ones" place, we need a signpost to tell us where we are. That signpost is a dot to the right of the "ones" place, separating whole numbers from fractional numbers, and we call it a **decimal point**. Numbers to the left of the "ones" place get progressively larger, while numbers to the right get progressively smaller.




Here are the place values for the number 456.789:

| 100 | 10 | 1 | point | 1/10 | 1/100 | 1/1000 |
|---|---|---|---|---|---|---|
| **4** | **5** | **6** | **.** | **7** | **8** | **9** |

The number is spoken as it's written: "four hundred fifty six point seven eight nine."

Again, if there is nothing in a particular place, we put in a zero. For example, if we're dealing with a number like six thousandths, we put zeroes in – this time to the *left* of the six – to hold the tenths and hundredths places. Six thousandths is written .006 in decimal form; that's a decimal point, two zeroes, and six. Ten and six thousandths would be 10.006 in decimal form.

$$\begin{array}{r} 10 \\ +.006 \\ \hline 10.006 \end{array}$$

Place holder zeroes to the right of the last integer are not necessary, but sometimes extra zeroes are added to show that a calculation has been carried out to extra places – in other words, it's very precise. 1.0000 inch indicates a measurement that is accurate to four places to the right of the point; that is, accurate to within 0.0001 inch.

The great benefit of working in decimal fractions is that the rules of integer arithmetic still apply. We can add and carry, subtract and borrow, multiply and divide the same way. We don't have to treat numbers to the right of the decimal point differently from numbers to the left of it.

Just a heads up – with European-made electronic equipment, decimal points may be shown differently in the diagrams. A comma may be used in place of a dot. With resistors, an R may indicate a decimal point. 4R7 would be 4.7 Ohms.

## LEADING ZEROES

Sometimes .006 is written 0.006 with a zero in the ones place. This is done where the number may be photocopied or viewed on a low-resolution monitor, and the decimal point might get lost. Since I don't know how you're viewing these study guides, I'm going to put those zeroes in. When you're doing your own calculations, you can use them or not as you choose.

optional ➡ 0.006

## CONVERTING A COMMON FRACTION TO A DECIMAL FRACTION

A common fraction can be viewed as an implied division. ¾ can be stated as "3 divided by 4." To convert to a decimal fraction, just go ahead and carry out the division. Punch in

**3**

then **/** (slash)

then **4**

then **=**

$$3/4 = 4\overline{)3} = 0.75$$

and the calculator will give you the answer:

**0.75**

We say "zero point seven five" or just "point seven five."

## VARIED TOPICS

Here's a grab bag of miscellaneous items that we have to get out of the way, before we get to scientific notation and algebra and similar good stuff.

## Orders of Magnitude

Each of the places in a number – 1's, 10's, 100's etc – represent an **order of magnitude**. A number that is "an order of magnitude larger" than another number is very roughly ten times larger. I don't know if there's any official convention, but anything from maybe 7 times to 20 times larger would be called "an order of magnitude larger." There's a pretty big fudge factor in there. Did I say math is precise? Yeah, but English isn't. So there.

## Significant Digits

Every digit is significant, but some more than others. The "2" in 2,000,006 signifies a much larger quantity than the "6." We call the digit furthest to the left the **most significant digit**, because it represents the largest quantity, and the digit furthest to the right the **least significant digit** because it represents the smallest.

These expressions are especially common in digital math which, you will be relieved to learn, doesn't come up until EM4.

## Increment and Decrement

An **increment** is a measured increase, a specific change from an existing point of reference that marks a new reference. If you have a savings account and you're depositing $50 per week, you're building it up in increments. A **decrement** is a measured decrease.

"Increment" or "decrement" means counting up or down by one – say, from 5 to 6 or 5 to 4 – unless, as in the example above, another amount is specified.

## Percentages

A **percent** is one hundredth of something ("cent" is a prefix meaning 1/100), indicated by the symbol **%**. A decimal number can be converted to a percentage by moving the decimal point two places to the right, adding place holder zeroes if necessary. Thus, 1 is 100%, 0.1 is 10%, 0.01 is 1%.

## Factoring

This means taking a number and finding the numbers that are multiplied to get it. You factor a number by finding a number it can be divided by, then finding a number the remainder can be divided by, and so on. When none of the remainders can be divided further without resulting in a fraction, you have found all the **factors**. For example:

$$\begin{aligned} & 24 \\ = & \ 2 \times 12 \\ = & \ 2 \times 2 \times 6 \\ = & \ 2 \times 2 \times 2 \times 3 \end{aligned}$$

Niether 2 nor 3 can be divided any further, except by 1 and by itself. So the factors of 24 are 2, 2, 2 and 3. If you multiply 2 x 2 x 2 x 3 you get 24.

Answers must be integers. 7 divided by 2 is 3.5, which is not an integer; thus 2 is not a factor of 7.

Not every number has factors. For example, there is no combination of numbers you can multiply to get 13. (Well, other than 1 x 13, but those don't count as factors.)

A number that has no factors except 1 and itself is called a **prime number**.

## Ratios

There are many cases in electronics where you have two of something – two voltages, two resistances, whatever – and the important thing is not the actual values but the proportional relationship between them. For example, as you will learn in chapter 8, if you have a 10V supply and you want 4V, one way to get it is to take a pair of resistors and divide the 10 volts between them. In theory, a 6Ω and a 4Ω resistor would do it, as would a 600Ω and a 400Ω resistor or a 30kΩ and a 20kΩ resistor. It is the proportional relationship, not the actual values, that gets us our 4 volts. I say “in theory” because in actual circuits, the results are affected by whatever else the resistors are connected to. But that's a complication that can wait until chapter 8.

This kind of proportional relationship is a **ratio** and it's written with a colon, like this:

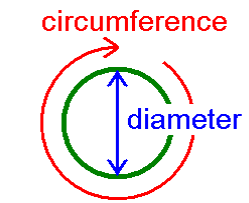
$$3:2$$

We say “three to two,” like racetrack odds.

## Irrational Numbers

An irrational number is not a number that needs psychiatric treatment. It is a number that cannot be precisely written as a ratio of two integers. Such a number also cannot be precisely written in decimal form.

One famous one is $\pi$, or **pi** (pronounced “pie”), which is the ratio of a circle's circumference (the distance around the circle) to its diameter. It's a bit more than 3, and that “bit” cannot be written down exactly, either as a ratio or a decimal number, no matter how many decimal places you use. 3.14 is close. 3.1416 is closer. 3.1415927 is pretty darn close. But you could calculate $\pi$ to thousands of places and still not nail it exactly.




$$\pi = \frac{\text{circumference}}{\text{diameter}} = 3.1415927...$$

Irrational numbers are not the only ones that can't be written precisely in decimal form. 1/3 is a rational number, since it's a ratio of integers. But in decimal form, it is 0.33333... and the 3's repeat endlessly.

To indicate a number that never ends, we use a series of dots. For example, the square root of 2 is 1.4159... Since we can't get perfect precision with a number like this, we have to be satisfied with “close.” So, how close is close enough? It depends on the situation. I'm going to talk about that in a bit, and just so you know, it's important.

## MORE ABOUT FRACTIONS

Most techs get into the habit of using calculators to convert common fractions to decimal fractions. But it's still worth understanding common fractions so you will know what you're doing.

## Dividing by Zero

A thing can be divided into 3, 4, 5 or 1,000 pieces, or it can be left in one piece, but it can't be in “zero pieces.” In other words, you can't divide a thing by zero. And, you can't have a fraction with zero for a denominator. A mathematician would say this condition is “undefined,” that is, there's no definition you can attach to it that isn't a logical contradiction.

Surprisingly, a lot of electronic calculations do wind up dividing by zero. For example, in a furnace igniter, the voltage produced is proportional to change in current divided by time, and time is zero. That would imply an infinite voltage. And, in fact, the voltage is very high – that's the whole point, we want to create a hot spark – but of course it isn't infinite. Because, in the real world, the parts we build stuff out of are different from the idealized parts we use to make calculations. So a divide-by-zero situation may not indicate something that's actually impossible, but it is a heads-up that the circuit's operation may be hard to control, and maybe the circuit should be redesigned.

## Reducing Fractions

It's considered good form to "reduce" a fraction if possible. $^{32}/_{64}$ is better written as ½. Here's an important fact that you'll use for a lot more things than just reducing fractions: **you can multiply or divide both numerator and denominator by any number you like, and you'll still have the same quantity in the end** – you will not have screwed up the fraction – **if you multiply or divide by the *same* number for both numerator and denominator**. There's an exception, of course: the number you divide by can't be zero.

Reducing a fraction involves finding a number that works as a factor for both numerator and denominator. For example, in the fraction 28/32, both 28 and 32 can be factored by 4, leaving 7 and 8 respectively. 8 can be further factored, but 7 can't be – it's a prime number – so we rewrite 28/32 as 7/8, which is its most reduced form. The quantity is still the same, but 7/8 is easier to deal with and less likely to trip you up when you're calculating.

## Multiplying a Fraction by an Integer

To multiply a fraction by N, multiply only its numerator by N. Example:

$$^{3}/_{8} \times 5 = {}^{15}/_{8} = 1^{7}/_{8}$$

## Multiplying a Fraction by a Fraction

Multiply the numerators, and separately multiply the denominators:

$$^{2}/_{3} \times {}^{3}/_{5} = (2x3) / (3x5) = {}^{6}/_{15}$$

Both numerator and denominator of 6/15 can be factored by 3, which permits us to reduce the fraction to 2/5. Note that this is less than either of the original fractions because, after all, it is a fraction of a fraction. This will always be true when you multiply two proper fractions.

## Adding a Fraction to an Integer

Change the integer to a fraction with the same denominator as the fraction you've already got by multiplying the integer by the number in the denominator; that becomes your numerator. 3 is 24 eighths, so:

$$3 + {}^{7}/_{8} = {}^{24}/_{8} + {}^{7}/_{8} = {}^{31}/_{8}$$

You're going to ask, Why do this when $3{}^{7}/_{8}$ is already in the correct form? Because ${}^{31}/_{8}$ is handier in calculations. Then, once you're finished with those calculations, you reduce the final fraction if you can.

## Adding Two Fractions

Fractions can be added if their denominators are the same. Then you just add the numerators. For example:

$${}^{3}/_{8} + {}^{5}/_{8} = {}^{8}/_{8} = 1$$

Three slices of pizza plus five slices are a whole pizza.

What if the denominators aren't the same? You make them the same. Remember, it's “legal” to multiply both numerator and denominator by a number; you still wind up with the same fraction. Take for example:

$${}^{2}/_{3} + {}^{3}/_{5} = ?$$

We make the denominators the same by multiplying *each* fraction by the *other's* denominator.

$${}^{2x5}/_{3x5} = {}^{10}/_{15}$$ (multiply 2/3 by 5)
$${}^{3x3}/_{5x3} = {}^{9}/_{15}$$ (multiply 3/5 by 3)
$${}^{10}/_{15} + {}^{9}/_{15} = {}^{19}/_{15} = 1{}^{4}/_{15}$$

Now that you know how to do this, file it away in the back of your mind. You won't need to use it when you have a calculator, as long as it is okay to state the answer as a decimal number, which it usually is. Just divide 2 by 3, yielding about 0.67. Put that in memory.

Divide 3 by 5, yielding 0.6. Add that to memory. Then do a memory recall, and you get the answer.

Did you try it? Did you get about 1.27? Good.

## RECIPROCALS

The reciprocal of 5 is $^1/_5$, or in decimal form, 0.2. You get the reciprocal of a number by dividing 1 by that number:

$$\textbf{Reciprocal of } N = {}^1/_N$$

You can leave the answer as a fraction, or you can punch $^1/_N$ into a calculator and push "=" to get the decimal equivalent. As you will see in later chapters, there are all sorts of ways you can use reciprocals to avoid more complicated calculation.

The reciprocal of a fraction is the same fraction, inverted:

$$\textbf{Reciprocal of } {}^A/_B = {}^B/_A$$

You can check to be sure you've done a reciprocal properly by multiplying the original number by the reciprocal. A number times its reciprocal is always 1, as in 3/8 x 8/3 = 24/24 = 1. The exception is a fraction where the numerator is zero, because of course the reciprocal would be a fraction where the denominator is zero, and that's taboo. But you wouldn't be bothering with a calculation anyway, because zero divided by any number is just zero.

## THE RECIPROCAL METHOD OF DIVISION

Dividing by a number is the same as multiplying by the reciprocal of that number, which is often a lot easier. For example:

$$\frac{12}{5}$$

is a little clumsy, but

$$12 \times 0.2$$

is simple.

Okay, it may not seem simple at first, because it's two operations: 12 x 2 = 24, times 0.1 = 2.4. (Missed that? 0.2 is 2 X 0.1, so 12 X 0.2 is the same as 12 X 2 X 0.1.) So, it's two *simple* multiplications, while 12/5 is long division. You can save a lot of calculation hassle, not to mention errors, if you get good at spotting opportunities to do this. Especially when the calculator isn't nearby, or your hands are full, and you have to do a quick division in your head.

## NESTED FRACTIONS

Sometimes you will run into a fraction of a fraction, as in

$$\frac{\frac{1}{3}}{8} \quad \text{or} \quad \frac{1}{\frac{3}{4}}$$

In theoery, the thing to do is multiply both sides of the fraction by the reciprocal of the fraction-of-fraction:

$$\frac{1}{\frac{4}{3}} \quad \begin{matrix} \times \frac{3}{4} \\ \times \frac{3}{4} \end{matrix} = \frac{\frac{3}{4}}{1} = \frac{3}{4}$$

In practice, it's easier to use the calculator to convert to decimals: ¾ = 0.75, 1/0.75 = 1.33333....

And that brings us back to irrational numbers, and the discussion I said we were going to have about how precise a number needs to be.

## PRECISION

As we saw with irrational numbers, it is not always possible to obtain a precise answer. Even when it is, it's often a waste of time and money. This is the really, really important issue I mentioned above, so I'm going to talk about it in some detail. Please pay close attention.

One of the ***greatest virtues a tech can possess*** is knowing what matters and what doesn't, and where the dividing line lies between doing something useful and just spinning your wheels. If someone puts the lid on a piece of equipment in such a way that the slots of the screws are all pointing in the same direction, you might view them as a perfectionist. I would view them as someone who is a complete stranger to common sense. When you're on your own time, you can talk idealism and perfectionism and gilding lilies all you want. When you're on the jobsite, you need to have a real-world attitude.

There are two factors which determine how precise you should aim to be: 1) how close to perfect it is possible to get in the situation you're in, and 2) how close to perfect it is worth getting.

**How precise you can be:** The theoretical limit to perfection is governed by the least perfect factor you have to work with. Parts values are not exact. For example, one of the most common electronic parts is a resistor, which we'll talk more about in the chapter on parts. Resistors are commonly specified with a 5% **tolerance**, which means their actual value can differ from their specificed value by up to 5%. If you're making a circuit with five parts in it, and one of them has a tolerance of 5%, specifying the other parts to an accuracy of 0.01% will still yield an overall accuracy no better than 5%. If 5% isn't good enough, you need to find a way to improve that part, rather than wasting your efforts where the problem isn't.

Likewise, if you're calculating values in a circuit made of parts with 5% tolerance, then your calculations can never be better than that. For example, a 1,000 ohm resistor with 5% tolerance could be as low as 950 ohms or high as 1050 ohms. If you calculate the current in that circuit to three-place accuracy, the resulting error may be as great as 5%. If you calculate to thirty-place accuracy, the error still may be as great as 5%. *You can't get a number that's more precise than the numbers you used to get it*. You can, however, waste a lot of time and effort. If I caught an employee doing this, I would regard that as proof they didn't understand what they were doing.

**How precise you should be**: this is a judgment call. I don't mean to encourage you to be sloppy, only to apply some common sense. I was once part of a job where dozens of amplifiers were specified where one would have sufficed, because the designer wanted to avoid the 10% change in signal level that might have occurred as

circuits were switched in and out. In this particular case, a 10% change would have been unlikely, but even if it happened, it could not have been detected except by a carefully trained user paying close attention under special test conditions which would never occur in actual operation. It was quite possible to get precision results – we did, in fact – but it took a lot of time, cost a lot of money, and aside from making the designer feel good, yielded a bit fat zero in actual benefits. In fact, the overall impact was negative: the system was much more complicated than it needed to be, sharply increasing the probability something would malfunction.

The answer to, “How good should I make it?” isn't always going to be the same. It might be worth gold plating the battery clips on a Ferrari, but not on a Ford. It's definitely worth putting expensive speakers in a home theater, but not in a bus terminal. The MVT (most valuable tech) is the one who can identify the point beyond which further improvement would cost more that it's worth. As a general rule, your goal should be a client who is:

- pleasantly surprised by the product's performance and build quality;
- not unpleasantly surprised by the price.

And, as a rule of thumb, take special care to do *very neat work*. Most clients don't have your technical knowledge, and can't evaluate system performance as intelligently as you can. So they are influenced a lot by the factor they do understand, which is how the system looks.

The exception is when the *customer* is a complete stranger to common sense. You have to be careful with a client who wants to buy $10,000 speaker cables. The uncharitable assessment is that a $10,000 speaker cable is a bald-faced fraud. A more charitable view might be that, though there may be real benefits to $10,000 cables, the same money spent elsewhere in the system would make a bigger difference. But if the customer is convinced, don't lose the job trying to re-educate him.

There's a lot more to this, and later EM modules and the various ETA certifications deal with specific examples. In the meantime, let's return to math.

## TRUNCATION AND ROUNDING

Limiting precision means dealing with only so many decimal places. Two decimal places gives an accuracy no worse than 10%, usually better; three places is accurate to 1% or better. How many places it's worth bothering with depends on the situation, as outlined above.

When there are more decimal numbers than we want to use, we throw away the ones we don't want. This is called **truncation**. The question then becomes, what do we do with the last number, the farthest one to the right? We **round** up or down, depending on what we've thrown away. The rule is, **if the most significant digit of the number we're throwing away is 5 or greater, we round up, othewise we round down.** So if we have a number like 7.654321 and we want to truncate it to two places, we throw away the 54321 and round up to 7.7. If we want to truncate 6.5432 to two places, we throw away 432 and round down to 6.5. Another example: 2/3, written decimally, is 0.6666666.... If we want to truncate it to three places, we round to 0.667 (the leading zero doesn't count as a “place”).

## ABSOLUTE NUMBERS

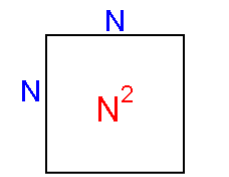
When writing math formulas, we may want to deliberately leave out any consideration of sign. A number with no sign is an “absolute” number, and it's written with a line on either side.

$|5|$, absolute 5, means a number that could be either +5 or -5. When someone goes to the trouble of specifying an absolute number, it means there's a good reason for leaving the sign out. For example, looking ahead to EM2, the average of an AC voltage is zero, because AC voltages alternate between positive and negative, many times each second. But if you've ever gotten a shock from something plugged into an outlet, you know very well that the actual voltage is *not* zero! It's usually specified as 117 volts. This is an absolute number. With AC voltages, it's customary to omit the vertical lines. They aren't necessary because an AC voltage number is *always* an absolute number.

Okay, so much for miscellaneous topics. Now we're going to study something that amounts to the bread and butter of math for technicians: **scientific notation**. We're going to kind of sneak up on it by starting with...

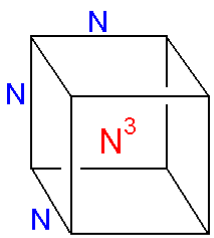
## POWERS OF NUMBERS

We often have to multiply a number by itself, and often more than once. The number of times a number is multiplied by itself is called the **power** of that number. For example, 4 x 4 x 4 x 4 x 4 is 4 to the 5th power. Sometimes people say X **raised to** such and such a power. The power is written as a superscript, which is a little number above and to the right of the number that is multiplied, e.g. 4 to the 5th power is $4^5$.
The little number is called an **exponent**.



area of a square

Two powers have special names: a number to the second power, that is, $\mathbf{N^2}$, is called **N squared.** A number to the third power, $\mathbf{N^3}$, is called **N cubed**. This is related to the fact that a square is a 2-dimensional area and a cube is a 3-dimensional volume.



volume of a cube

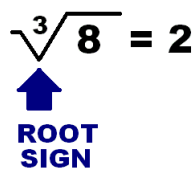
N to the first power, $N^1$, is the number N itself, as in:
$\mathbf{6^1 = 6}$. N to the zeroeth power, $N^0$, is 1, as in: $\mathbf{6^0 = 1}$.

As usual, zero is the exception. 0 to any power is 0.

## NUMBER ROOTS

A root is the opposite of a power. If you take a number N and multply by itself, you get a power of N. A **root** is the number that you multiply by itself to *get* N. For example, 5 x 5 = 25. So, 25 is the square of 5, and 5 is the square root of 25. 5 is the 4th root of 625, which is to say, 5 x 5 x 5 x 5 = 625.

The root symbol is shown to the right. The number under the line is the number whose root we're trying to find, and the little number in the notch is the number of the root. In this case, the symbol indicates the 3rd or cube root of 8 which, as you see, is 2. That means, if you multiply 2 three times, 2 x 2 x 2, you'll get 8. If we're finding a square root, the number in the notch is omitted. It's assumed that the symbol means a square root unless some other number is specified.




So how do you calculate a square root? You don't. There's no easy way of doing it. Just be sure you always have a calculator with a square root key.

A root can also be written as an exponent. When a root is written as an exponent, it takes the form of a fraction. $N^{1/2}$ is a square root, $N^{1/3}$ is a cube root, and so on. Of course, a fraction can always be expressed as a decimal number. A square root, in decimal form, is $N^{0.5}$, a cube root is $N^{0.33...}$, a fifth root is $N^{1/5}$ or $N^{0.2}$.

## NEGATIVE EXPONENTS

An exponent can be negative, as in $N^{-3}$. A negative power of a number is the same as the positive power of its reciprocal. For example, the reciprocal of 5 is 0.2, so $5^{-3}$ is the same as $0.2^3$. This is handy to know because even scientific calculators, and especially calculator functions on computers, often cannot handle negative exponents. It's also handy to know because it impresses other techs, who often don't know how to do this.

## POWERS OF TEN

At the beginning of this chapter, we talked about decimal places – the ones place, the tens place, the hundreds place and so on. We also talked about places to the right of the decimal – the tenths place, the hundredths place and so on.

Now what we've talked a little about powers, you're in a position to understand that **decimal places represent powers of ten**. For example, 1000 is $10^3$; that is, 10 x 10 x 10. Every place left or right of the decimal represents a power of 10:

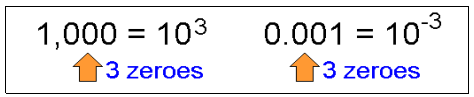
| | | |
|---|---|---|
| **1** | | $= 10^0$ |
| **10** | | $= 10^1$ |
| **100** | $= 10 \times 10$ | $= 10^2$ |
| **1,000** | $= 10 \times 10 \times 10$ | $= 10^3$ |

...and so on. Going the other way, into smaller numbers, the exponents go negative:

| | | |
|---|---|---|
| **0.1** | $= {}^1/_{10}$ | $= 10^{-1}$ |
| **0.01** | $= {}^1/_{10} \times {}^1/_{10}$ | $= 10^{-2}$ |
| **0.001** | $= {}^1/_{10} \times {}^1/_{10} \times {}^1/_{10}$ | $= 10^{-3}$ |
| **0.0001** | $= {}^1/_{10} \times {}^1/_{10} \times {}^1/_{10} \times {}^1/_{10}$ | $= 10^{-4}$ |

...and so on. As you work with electronic calculations, powers of ten will become as natural as breathing.

Here's a rule of thumb you're going to find extremely useful: **The number of zeroes is the same as the number of the exponent.** With a decimal fraction, you need to include the leading zero for this rule to work.




## MULTIPLYING POWERS OF TEN

To *multiply* powers of ten, you *add* the exponents. For example:

$$100 \times 1{,}000 = 100{,}000$$

Rewritten with exponents, 100 is $10^2$, 1000 is $10^3$, and 100,000 is $10^5$. So:

$$10^2 \times 10^3 = 10^5$$

It works the same if one or both exponents are negative:

$$1{,}000 \times .01 = 10^3 \times 10^{-2}$$
$$= 10^1$$
$$= 10$$

Remember, adding a negative number is the same as subtracting a positive number: 3 -(+2) = 1.

To *divide* powers of ten, *subtract* the exponent:

$$10^6 / 10^2 = 10^4$$

In some cases you may find it easier to use reciprocals and multiply. The reciprocal of a positive exponent is a negative exponent, and vice versa. For example, from our study of reciprocals you can deduce that one million divided by one hundred is the same as one million multiplied by one hundredth. In exponential form,

$10^6 / 10^2$ is the same as $10^6 \times 10^{-2}$, or $10^4$.

Use of powers of 10 is immensely valuable in electronics, because we routinely deal with large positive and negative powers of 10. It's a lot easier to write $10^6$ than 1,000,000. More important, it's a lot easier to make calculations and not make mistakes. Just try multiplying 10,000,000 by 0.00000001 without slipping a decimal place! Go ahead, I dare you. But $10^7 \times 10^{-8}$ is a snap. $10^{-1}$, right.

## MULTIPLYING 10'S BY MOVING THE DECIMAL POINT

Let's go back to decimal numbers and pick up something that wouldn't have made sense to you before, but will now. In electronics, you often have to multiply or divide a decimal number by some power of 10, as we were just doing. Now that we understand that each decimal place represents a power of ten, we can see that multiplying or dividing any number by a power of 10 amounts to simply moving the decimal place right or left. Specifically, **to multiply, move the point right; to divide, move it left.** For example, 100 is $10^2$. To multiply a decimal number by $10^2$, move the decimal point right two places, e.g. to multiply 6.235 by $10^2$, move the decimal 2 places to the right, with 623.5 as the result. This is a lot simpler than making actual calculations. Simple is good. We like simple. Let's hear it for simple. Yay, simple.

The rule in bold above will become second nature, but in the meantime, here's a crutch: moving the decimal point to the **R**ight **R**aises the exponent, e.g. 10.00 becomes 100.0 which is to say $10^1$ becomes $10^2$. Moving the point to the **L**eft **L**owers the exponent.

## SCIENTIFIC NOTATION

Yay, we're here! This is where you learn to handle the monstrous and miniscule numbers electronic techs run into all the time.

It's all well and good to use powers of ten when we're dealing with numbers like 1, 10, and 100. But what about a number like 33,000?

We deal with this by recognizing that 33,000 is 33 x 1,000, or better for our purposes, 3.3 x 10,000. 10,000 is$10^4$, so 33,000 can be written as 3.3 x $10^4$. This is called **scientific notation**. Let me put that all on one line so the number transformation is clearer.

$$\mathbf{33{,}000 = 3.3 \times 10{,}000 = 3.3 \times 10^4}$$

If there were more integers, and we wanted the precision, we would extend the decimal fraction as far as needed, as in:

$$\mathbf{3.32546 \times 10^4}$$

A number written in scientific notation is:

- one number to the left of the decimal
- however many numbers are necessary to the right of the decimal
- a power-of-ten multiplier.

If the number is less than one, as in 0.0033, we do the same thing, but the power-of-ten exponent will be negative. 0.0033 is 3.3 x $10^{-3}$. Observe that 0.0033 is 3.3 x 0.001. 0.001 – count the zeroes – is $10^{-3}$.

This is a good time to bring up a rule: **If you do something to a number, and then do the opposite thing to it, you'll be back to the same number you started with.** Duh, ya think?

Like many math rules, that's a seemingly stupid-simple statement that turns out to be very useful: If you do something and then do its opposite, you won't have screwed up the calculation. So, suppose we multiply 3.3 by 10, then divide it by 10. That should be legal, right? 3.3 X 10 is 33, and 33 multiplied by 1/$10^{th}$ is 3.3 again: So:

$$3.3 = 33 \text{ X } 0.1 = 3.3$$

We can keep doing this as long as we like:

$$3.3 = 330 \text{ X } 0.01$$
$$= 3{,}300 \text{ X } 0.001$$
$$= 33{,}000 \text{ X } 0.0001$$

...and so on. This also works with decimal fractions: if we multiply 0.0033 by $10^3$ we get 3.3, so we can say that 0.0033 is the same as 3.3 X $10^{-3}$. Okay, I can see your eyes glazing over. Go outside and take a few deep breaths, then come back and read this paragraph again. I'm not just trying to make your mind jump through hoops for my own twisted amusement. A tech winds up doing this stuff all the time.

Converting decimal numbers to scientific notation is where multiplying by moving the decimal point comes in handiest. Make up some exercises and practice this. In about ten minutes you will be able to do it with half your brain tied behind your back.

In scientific notation, high-precision numbers with lots of digits are almost always truncated. A number like 1,234,567 would be 1.234567 x $10^6$ in scientific notation, which seems pointless.

However, that represents a number written out to 0.0001% accuracy, which you almost never need. In the real world, you would almost always truncate this to 1.2 x $10^6$ or maybe 1.23 x $10^6$. See, scientists are a practical bunch after all.

## MULTIPLICATION USING SCIENTIFIC NOTATION

Scientific notation becomes super-valuable when you start making calculations. Suppose we have to multiply

$$27{,}000 \times 0.0035$$

which is a typical electronic calculation. Go ahead, try doing it in decimal form, you'll be lucky not to slip a digit one way or another. But in scientific notation, this problem is written as

$$2.7 \times 10^4 \times 3.5 \times 10^{-3}$$

The multiplications can be done in any order – that's a rule we're going to talk about in a bit – so let's rearrange the numbers:

$$2.7 \times 3.5 \times 10^4 \times 10^{-3}$$
$$= 9.95 \times 10^1$$
$$= 99.5$$

Since 99.5 is within 0.5% of 100, we'd probably just take 100 as our answer.

## PREFIXES

To simplify the writing of powers of ten, a **prefix** is assigned to every increment of 1,000 times or $10^3$x change. You're already familiar with some of those. “Kilo,” as in kilogram, means one thousand; “Mega,” as in megawatt, means a million, and so on.

It's normal for people to deal with large numbers of things by thinking in terms of bigger chunks. We don't say 6,000 pounds, we say 3 tons. A “ton” is a specific quantity, 2,000 pounds of weight. But “kilo,” as a prefix, can be used for anything: kilogram, a thousand grams of weight, kilowatt, a thousand Watts of power, kilohm, a thousand Ohms and so on. Prefixes allow us to get rid of a lot of zeroes by changing the scale of the quantities we're dealing with.

Note that, to the left of the decimal point, digits are arranged in groups of three, separated by commas. These groups correspond to the prefixes. For some reason, commas are not used on the right side of the decimal point. This means that if you ran into a number like 0.0000035, you'd have to count the zeroes carefully. But numbers like that are seldom written that way to begin with. They're written in scientific notation, or they're written with prefixes.

Here's a chart with the most common prefixes. This chart is repeated in the review chapter so you can print it out.

*Prefixes*

| Quantity | Decimal Number | Power | Prefix | Abbrev. |
|---|---|---|---|---|
| Trillion | 1,000,000,000,000 | $10^{12}$ | "Tera" | T |
| Billion | 1,000,000,000 | $10^{9}$ | "Giga" | G |
| Million | 1,0000,000 | $10^{6}$ | " Mega" | M |
| Thousand | 1,000 | $10^{3}$ | " kilo" | k |
| One | 1 | $10^{0}$ | | |
| Thousandth | 0.001 | $10^{-3}$ | " milli " | m |
| Millionth | 0.000001 | $10^{-6}$ | " micro" | μ |
| Billionth | 0.0000000001 | $10^{-9}$ | " nano" | n |
| Trillionth | 0.0000000000001 | $10^{-12}$ | " pico " | p |

Larger ↑ Smaller ↓

Note that one quantity, micro, is denoted by a Greek letter, mu. Nobody's going to sue you if you write “u” instead of “μ,” lots of people do it.

Note also that prefixes smaller than one are denoted by lower-case letters, and prefixes larger than one by upper-case letters. That's how we tell “Mega” and “milli” apart. The exception is “kilo,” with a small k. Darned if I know why they did that.

For orders of magnitude between two prefixes, we keep the next lower prefix and use numbers 1, 10 and 100 like this:

**$10^{3}$ = 1 kilo**
**$10^{4}$ = 10 kilo**
**$10^{5}$ = 100 kilo**

Then we start over:

**$10^{6}$ = 1 Mega**
**$10^{7}$ = 10 Mega**
**$10^{8}$ = 100 Mega**

...and so on.

## CONVERTING FROM ONE PREFIX TO ANOTHER

One of the things you're going to have to do all the time is convert between numbers written with different prefixes. Consider three levels of current flow: 0.003A, 3mA, 3,000μA. If you know your prefixes, you'll be able to figure out that all three are the same amount of current.

When you have to convert between prefixes, use the technique of moving the decimal point. Since prefixes denote increments of three orders of magnitude, you shift the decimal point three places right or left.

Rules of Thumb:

**If converting from a smaller prefix to a larger prefix, e.g. kilo to Mega, move the decimal point to the left, three places at a time:**

**10,000kW = 10.000MW.**

**If converting from a larger prefix to a smaller prefix, e.g. milli to micro, move the decimal point to the right, three places at a time:**

**2.2mA = 2,200μA.**

**The smaller the prefix unit, the larger the number becomes:**

**1W = 1,000mW = 1,000,000μw**

**The larger the prefix unit, the smaller the number becomes:**

**1,000,000W = 1,000kW = 1MW**

Here are four exercises to give you some practice with converting quantities.

**Example #1 : Convert 2000pA to μA**

Choices:
A. 2 μA
B. 0.002 μA
C. 0.02 μA
D. 0.2 μA

SOLUTION: There are 6 exponential values between pico and micro; a pA is $10^{-12}$A and a μA is $10^{-6}$A. Micro is larger than pico. Shift the decimal point 6 places to the left.

$$2000pA = 0.002\ \mu A$$

Choice (B) is the answer. The three zeroes to the right of the “2” are discarded since we don't need them to hold places any longer.

**Example #2 : Convert 15 KV to Volts**

Choices:
A. 15V
B.150V
C.1500V
D. 15,000V

SOLUTION: To convert kiloVoltsto Volts, shift the decimal point three places to the right.

$$15\ KV = 15{,}000\ Volts$$

Choice (D) is the answer

**Example no. 3: Convert 500,000Ω to MegOhms**

Choices:
A. 500MΩ
B. 50MΩ
C. 0.5MΩ
D. 500,000MΩ

SOLUTION: Remember that to convert a smaller unit to a larger one, shift the decimal point to the left. Converting from kilOhms to MegOhms is like dividing the kilOhms by 1,000 or shifting the decimal ponit three places to the left.

$$500\ k\Omega = 0.5\ M\Omega$$

Choice (C) is the answer.

**Example #4: Convert 200mA to A**

Choices:
A. 2 A
B. 0.2 A
C. 0.02 A
D. 0.002 A

SOLUTION: Shift the decimal point to the left 3 places is equivalent of dividing by $10^{3.}$

$$200mA = 0.200\ A = 0.2A$$

Choice (B) is the answer.

## EQUATIONS

An equation is nothing more than a statement that something is the same as something else. That's what the equal sign means.

$$\text{Frigid} = \text{Very Cold}$$ is an equation.

More broadly, an equation is a mathematical way of saying, “here is something, and here is what it means.”

The simplest equations are the arithmetic operations we've already been doing, converted to equation form.

$$\begin{array}{r} 6 \\ \underline{-4} \\ 2 \end{array}$$

can be rewritten as an equation this way:

$$6 - 4 = 2$$

An equal sign can also be used to label a quantity, as in

$$R = 240\Omega.$$

## ALGEBRA

The equation is the mathemetician's Swiss army knife, the basic multi-purpose tool. What makes it so useful is that, by moving numbers around, we can solve problems and find unknown numbers.

The problem with moving numbers around within an equation is that you run the risk of starting with an equation that’s true and ending up with an equation that’s false. To keep that from happening, you have to obey established rules which mathemeticians have already proved to be correct. Each rule is a tool in that Swiss army knife that lets you do a specific thing in an equation. When you're done, you have a different equation that is still valid – it still tells a truth – but it tells a different truth, and gives you data you didn't have before.

**Algebra** is the branch of mathematics that deals with finding, proving, and applying the rules about equations. The most basic rules, the ones we'll be using, are of the common sense, “well, duh!” variety; so obvious you wonder why I bothered pointing them out. Because they're your tools, that's why, and the fact that they're obvious doesn't keep them from being powerful.

The nice thing about algebraic rules is that they work with *any* numbers, or in some cases, any numbers except zero. In fact, when we state the rules, we don't use numbers at all. We use letters that stand for numbers, to make it easier to see how the rule works without getting sidetracked by specific quantities.

## VARIABLES

A letter that stands for a number is called a **variable** or a **general number.** As its name implies, its value can be varied. “3” is always three, but “N” can be three, nine, a dozen, a gross or whatever. We can write an equation using variables that properly obeys an algebraic rule, then replace some of the variables with actual numbers and see what happens.

Any letter can be used as a variable, but it's good to stay away from a letter that is comonly used to mean a specific thing, unless we *want* it to mean that thing. For example, you wouldn't usually choose “W” to use as a variable, because it implies that the variable denotes a power level in Watts, which may not be the case. However, if you actually are calculating a power level, then of course you'd write “W” for that variable.

Where there is more than one thing that uses the same letter, a number is added, either full size or as a small number called a **subscript**. For example, a particular piece of electronic equipment may have dozens of resistors in it. In the schematic diagram, they will be identified as R1, R2 etc, or as $R_1$, $R_2$ etc.

Now we can expand our idea of what an equation is: an equation defines a *relationship*. If you have several numbers that relate to each other in a certain way, and you change one of the numbers, the other numbers will change as a result, and the equation tells you how.

I hinted at one of those in Chapter 1. Recall that, in a simple circuit with a voltage source and a resistance, the voltage and resistance determine the current flow. If voltage goes up, current goes up. If resistance goes up, current goes down. The equation that describes this relationship, where E (or V), I and R are the variables, is called Ohm's Law, and we will study it in Chapter 4.

Once we have a particular relationship defined by a general equation, we can replace some of the variables with actual numbers which we have chosen, or which are dictated by the situation. For example, if we're dealing with a car's electrical system, the voltage is already known: a car runs on about 12 volts. So, in any equation where a "V" variable denotes a voltage, and we're talking about a car, we can take out V and write in 12.

The purpose of this kind of substitution is to obtain an equation where all the variables have been replaced by numbers except one, the number we don't know and are trying to find. This number is called the **unknown** for obvious reasons. Then we use the equation and the rules of algebra to find the unknown number – we **solve for** that variable. The reason we use the expression "solve for that variable" is that, in some cases, we can choose which quantity we want to solve for, e.g. we can change current by changing either voltage or resistance.

## RULES FOR EQUATIONS

The rules are usually stated in if/then form. We'll start with these.

### Rule 1: If a = b, then b = a.

In other words, if frigid is the same as very cold, then very cold is the same as frigid. Duh. I told you math is easier than it looks. The general principle, stated in words: you can swap the numbers on either side of the equals sign. If they're the same to start with, they'll be the same afterwards. You have to swap *all* the numbers. There are other rules, a little more complicated, to use when you want to swap just one.

### Rule 2: If a = b, then a + x = b + x.

In other words, if two quantities are equal and you increase (or decrease) both by the same amount, they will still be equal. If you and I both have $1,000 in the bank and we both deposit $300, we'll both have $1,300.

### Rule 3: If a=b, then ax = bx.

If two quantities are equal and you multiply (or divide) both of them by the same amount, they will still be equal. Example: if 4x = y, then 12x = 3y. Four quarts = one gallon; twelve quarts = 3 gallons.

Note that, when multiplying variables, we don't use the "x" symbol, in part because "x" is often used as a variable. When you see two variables next to each other, or a variable and a number, you multiply them.

In electronics, you'll routinely run into equations where there are more than one number on either side of the equal sign. Each of these is called a **term**.

In the equation below, there are four terms: A, B, C, D.

$$AB = C + D$$

Now we have to start being careful. Recall the rule that it's legal to do anything you want to an equation as long as you do the same thing to both sides. That means doing the same thing to the *whole* left side and the *whole* right side. Here are the rules for that.

## Rule 4: to add a number to both sides of an equation, simply add.

Example: to add 3 to the equation above, add 3 to each side.

$$AB = C + D$$

becomes

$$AB + 3 = C + D + 3$$

Each side of the original equation, taken as a whole, represents a single quantity. On the left it's the result of a multiplication, on the right it's the result of an addition. But when all is said and done, the equation says the two sides are equal, so if you add three to both, they'll still be equal. The same rule applies to subtraction, of course.

## Rule 5: to multiply a product by a number, simply multiply.

3 times AB = **3AB**

This can be thought of as multiplying A x B, then multiplying the product by 3. The rule also applies to division.

**Rule 6: to multiply a sum by a number, multiply each of the terms by the number.**

$$3(C + D) = 3C + 3D$$

Separately multiply each term by the multiplier number. If you want three peanut butter sandwiches, you need three sandwiches' worth of bread *and* three sandwiches' worth of peanut butter.

The same rule applies to division:

$$\frac{C + D}{3} = \frac{C}{3} + \frac{D}{3}$$

## ORDER OF OPERATIONS AND GROUPING

When adding or subtracting a bunch of numbers, it doesn't matter what order you do them in. In fact, when adding a series of numbers, the standard method of checking is to add them again, starting at the other end. Likewise, when multiplying or dividing a bunch of numbers, you can do them in any order. the order doesn't matter.

However, in many other calculations, especially ones that mix addition/subtraction and multiplication/division, it matters a whole lot what you do first. For example, take

$$3 + 2 \times 6$$

If you add 3 + 2 to get 5, then multiply by 6, the final answer is 30. If you multiply 2 X 6 to get 12, then add 3, the final answer is 15. So, what are the rules?

**Rule 7: when you have both multiply/divide operations and add/subtract operations, do the multiply/divide operations first.**

In the above case you would first multiply 2 X 6 and add 3 to the result, so the correct answer is 15.

**Rule 8: Where the proper order is not obvious, or is contrary to the general rule, parentheses are used to "group" the operations to be performed first.**

If the previous problem had been written

$$(3 + 2) \times 6$$

that would have meant you were to add 3 + 2 first and then multiply the sum by 6.

## ISOLATING AN UNKNOWN

Usually, the whole purpose of moving variables around is to get a single unknown all by itself on one side of the equal sign. Everything else is on the other side of the equal sign, and if you know all those quantities, you can find the value of the unknown.

To show you how this works, I'm going to take you step-by-step through a real-world example. The general form is equation 1 above right. We happen to know, in this particular case, that X is 8 and f is 1,000. So we substitute those values (equation 2) . Now all the quantities are known except C, so our job is to move things around until we get a simple equation with C on the left side.

First things first: we have a $10^6$ above the line and $10^3$ below it, and we can simplify that. Remember that you can do anything you want to a fraction, as long as you do the same thing to both numerator and denominator. In this case, we're going to multiply them both by $10^{-3}$ (equation 3). In the numerator, $10^6 \times 10^{-3} = 10^3$. In the denominator, $10^3 \times 10^{-3} = 10^0$, which is 1. Any time you see "multiply by 1" in an equation, you can just drop that out, because a number multiplied by 1 is just itself. Using this kind of top/bottom multiplication to eliminate terms is called **cancelling**. In equation 4, we've gotten rid of one term entirely, making the equation simpler. Simple is good. We like simple. Yay, simple.

$$\mathbf{1} \quad X = \frac{10^6}{6.3 \times f \times C}$$

$$\mathbf{2} \quad 8 = \frac{10^6}{6.3 \times 10^3 \times C}$$

$$\mathbf{3} \quad 8 = \frac{10^6}{6.3 \times 10^3 \times C} \frac{(10^{-3})}{(10^{-3})}$$

$$\mathbf{4} \quad 8 = \frac{10^3}{6.3 \times C}$$

$$\mathbf{5} \quad 8C = \frac{10^3}{6.3 \times C} C$$

Now, we have to isolate "C" on the left side. First, we multiply both sides of the equation by C. On the left, that gives us 8C (equation 5). On the right side, remember that to multiply a fraction by a number, you multiply only its numerator by that number. So we wind up with a C above and a C below the line, or C divided by C.

That lets us cancel the Cs, leaving us with equation 6.

$$\mathbf{6} \quad 8C = \frac{10^3}{6.3}$$

$$\mathbf{7} \quad C = \frac{10^3}{6.3 \times 8}$$

$$\mathbf{8} \quad C = \frac{10^3}{50} = 20$$

Finally, we divide both sides of equation 6 by 8. On the left, that gives us 8C divided by 8. The 8s cancel, leaving us with C. On the right, we call up our old friend the reciprocal. Sharp dudes that we are, it occurs to us that multiplying the denominator by 8 is the same as dividing the numerator and thus the fraction by 8. So we do that, leaving us with equation 7.

Now we've got C isolated on the left, and no unknowns on the right. All that's left is to multiply 6.3 by 8, which is approximately 50, and then divide $10^3$ by 50, which gives us a final answer (equation 8): C = 20.

What we've been doing, by the way, is designing part of an 8-ohm speaker system, specifically part of a dividing network that sends bass to the woofer and treble to the tweeter. I've done this myself dozens of times.

The most fundamental electrical calculation, Ohm's law, often takes the form of an unknown on one side and a fraction on the other, so you're going to get lots of practice at this.

## SUBSTITUTION

This has been implied alredy, but it should be stated explicitly.

**Rule 9: if a quantity is equal to another quantity, then any time you see one of them, you can put the other one in its place.**

If A = BC, then A + N can be rewritten BC + N. You'll use this a lot in the next chapter.

## INEQUALITIES

Sometimes we deal with numbers that are *not* equal. We use the “greater than” sign, >, and the “less than” sign, <, to show that some numbers are larger than others.

**a > b** a is greater than b.

**4 < 5 < 6** 4 is less than 5, which is less than 6.

If the differences are great, we double the signs: >> means “a lot greater than” and << means “a lot less than,” as in

$$1 << 1{,}000 << 1{,}000{,}000$$

In practical terms, the doubled symbol means that one quantity is so much smaller than another that it is not worth bothering with. This effectively eliminates some terms from equations, simplifying the analysis of complicated systems. Simple is good. We like simple. Yay... okay, I'll quit now.

## FUNCTIONS

Mathematicians often say things like, “Y is a such-and-such function of X,” which is the kind of math-speak that makes some students decide to give up and go into lawn maintenance. But the statement is just a mathematical way of saying something everybody already knows: there are a lot of times when, if something happens, it makes something else happen. Cause and effect, in other words.

For example, if the probability of rain goes up, the percentage of people who carry umbrellas goes up. The percentage of people carrying umbrellas is a **function** of the probability of rain.

Let's look at equations again. Take one like

$$y = 3x.$$

We know that this states an equality and a ratio. But we can also look at it as a statement that one quantity *controls* another quantity in a certain way. Usually, the quantity that is controlled is placed on the left side of the equal sign, and whatever controls it is placed on the right. In this example, x controls y. If x happens to be 25, that makes y 75. It's a cause/effect relationship, where X is the cause and Y is the effect. In other words, Y is a function of X.

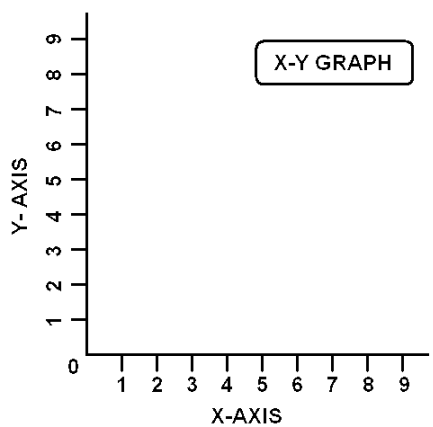
Y can be related to X in an infinite number of ways. Y can equal X, or 3X, or $X^2$, or X+1, or whatever. A quantity can even be a function of more than one variable. We've briefly looked at one of those already: current depends on voltage and resistance. That is the most fundamental function in all of electronics.

If electronic quantities can be related by a mathematical function – if the way one quantity affects another can be expressed as an equation – then anyone who knows how to work with equations can develop an almost wizard-like ability to analyze and control electronic circuitry.

## X-Y GRAPHS

The X-Y graph is a rectangular space for displaying data. The horizontal line along the bottom is called the **X axis**, while the vertical line along the left side is called the **Y axis** – thus the reason for the name of the graph.

These lines are typically marked off in increments associated with numbers. In other words, the X-axis and Y- axis are just glorified number lines. The increments and the numbers on the X-axis can be different from those on the Y-axis.

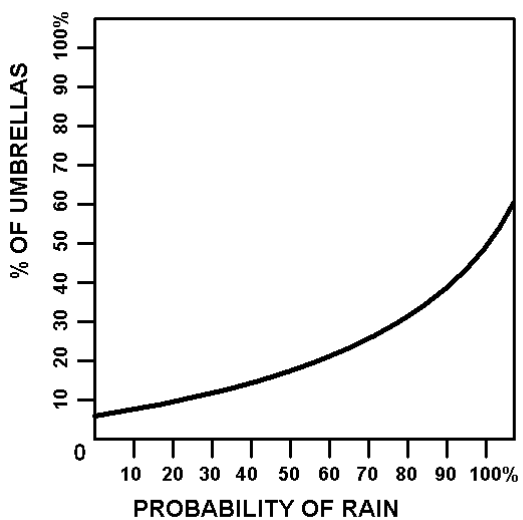



But one number is usually the same. The lower left corner of the graph, where the X and Y axes intersect, is usually zero on both. ("Axes," meaning chopping tools, is pronounced "ACK-sez." "Axes," meaning lines on a graph, is pronounced "ACK-zeez.") Since the zero corner is the anchor, the starting point for both X and Y axes, it is called the **origin** (OR-ijin).

Very often, the purpose of an X-Y graph is to display a function, which as we've said is a cause/effect relationship. The cause is usually plotted along the X-axis, and the effect is plotted along the Y-axis.
Let's go back to our umbrella example. In this case, the controlling quantity is the probability of rain, stated in percentages. When there is essentially no possibility of rain – there are places on Earth so dry no rain has ever been recorded – the probability is zero. When it's raining, the probability is 100%. This controlling quantity is plotted on the X axis. The quantity controlled is umbrellas, again stated in percentages, and plotted on the Y-axis.

Suppose we've collected a lot of data. We put it into the graph by making marks in the rectangular space. To find the right place for each mark, we find the chance of rain on the X-axis and draw a vertical line from that point. This is called the **X coordinate**. Then we find the percentage of umbrellas on the Y-axis and draw a horizontal line from that point. This is called the Y coordinate. Where the lines intersect, we put a dot. Every dot we put on the graph this way represents a specific correlation between X and Y. When we've got enough dots, we draw a line to connect them all.

This line displays the function: umbrellas as a function of the probability of rain – Y as a function of X. There's no law that says the line must start at the origin, or must be a neat, straight line. If we really did go ahead and collect the data, the resulting X-Y function would probably look like the curved line in the graph at left, with the percentage of people carrying umbrellas rising sharply as storm clouds gather.

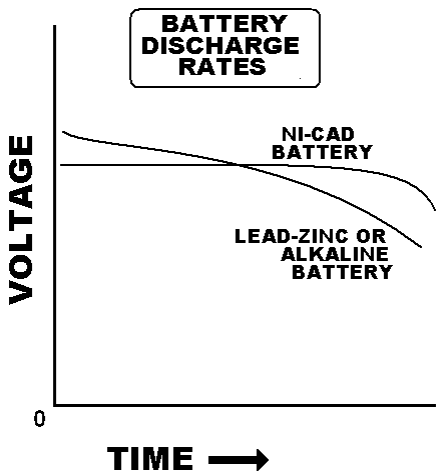



Mathematicians indicate a particular pair of x and y coordinates by parentheses: **(x,y)**. If Y=3X, then some coordinate pairs would be (2, 6), (3,9) and (8,24).

A graph gives us a picture of data, and as the saying goes, a picture is worth a thousand words. We can learn a lot at a glance: a few people carry umbrellas all the time, it takes the threat of an imminent storm to get people to carry umbrellas, many people don't carry umbrellas even when it's raining, etc.

A graph can have more than one line, showing more than one function. This is especially useful when we want to make a comparison. For example, in electronics one of the most common uses for an X-Y graph is to show how voltage changes with time. We all know that as a battery discharges, its voltage drops. Different kinds of batteries have different discharge characteristics, which we will study in Chapter 10.

Here's a graph showing the discharge characteristic of a carbon-zinc battery compared to a nickel-cadmium battery under certain specified conditions. At a glance, we can tell that the voltage of a carbon-zinc battery starts higher, but drops as the battery is discharged, while the voltage of a NiCad battery stays relatively constant until it's almost completely discharged. This means, among other things, that it's hard to design a meter to show how much charge is left on a NiCad battery.




Hey, guess what! We're done with calculations! Just one more topic, about units of measure.

## METRIC CONVERSIONS

You will often run into **SI units**, the international standard measurement units based on the metric system.

Electrical quantities are the same all over the world. Volts, Amps, Ohms, Watts, Coulombs, Joules etc need no conversion.

The two units you will most often need to convert are size and weight. The basic metric unit of length is the **meter**, spelled **metre** in most places outside the USA. A meter is 100 centimeters or 1,000 millimeters.

Conversions:

**1 meter = about 3.28 feet**
**1 foot = about 0.305 meter**
**1 centimeter = about 0.394 inch**
**1 inch = about 2.54 centimeters**

A meter is about a yard plus $3\frac{3}{8}$ inches.

The basic metric unit of weight is the **kilogram**, which is 1,000 grams. Conversions:

**1 kilogram = about 2.2 pounds**
**1 pound = about 0.455 kilograms**
**1 gram = about 0.035 ounce**
**1 ounce = about 28.3 grams**

***End of Chapter 3***

# EM1 Chapter 4
# OHM'S & WATT'S LAWS

**by Karl Eilers**

*Objectives of this chapter:*

- *Explain the characteristics of DC resistance.*
- *Summarize Ohms law.*
- *Calculate current, voltage and resistance using Ohms Law.*
- *Describe Watts Law*
- *Calculate power in a DC circuit using Watts Law.*
- *Define Joule and kilowatt-hour as energy units.*

Galileo got in trouble for saying everything revolves around the Sun. He was eventually proved right, but in electronics everything revolves around Ohm's Law. Yes, it's that important. I hope you're wide awake.

## VOLTAGE, CURRENT, RESISTANCE REVIEW

In chapter 1, you were introduced to the three quantities involved in Ohm's Law: voltage, current and resistance. To review:

**Current** is the mass movement of electrons through a conductor (and sometimes through space). In equations it is represented by the letter "**I**" for "**intensity**" of current flow. It is measured in **Amperes**, or **Amps** or "**A**" for short.

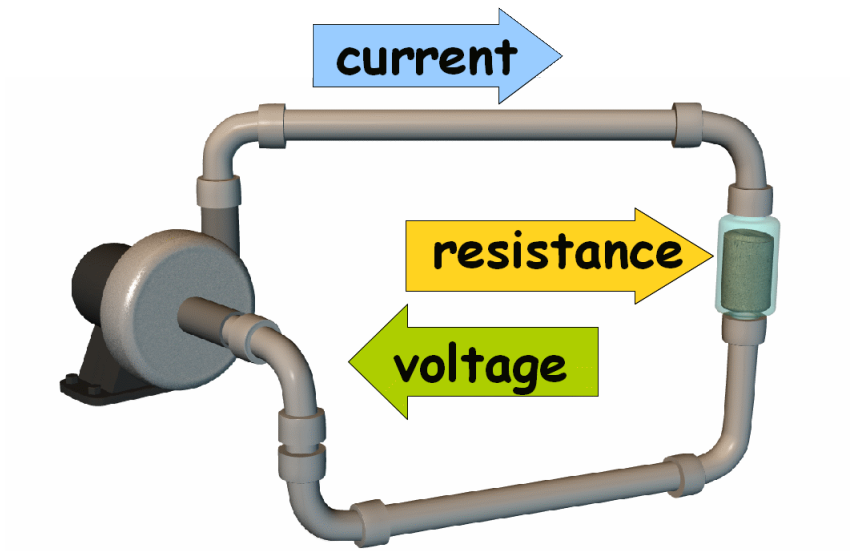
**Voltage** is the "push" that makes electrons move, which is why its formal name is "electro-*motive* force." In equations it is represented by the letter "**E**" or, more often, "**V**." It is measured in **Volts**, abbreviated "**V**." It is the result of the fact that electrons are negatively charged, and tend to move away from negatively charged objects and toward positively charged objects. The difference in charge between two objects is called a **potential**.

**Resistance** is a kind of "friction" that interferes with electron movement. In equations it is represented by the letter "**R**." It is measured in **Ohms**, represented by **Ω**, the Greek letter Omega. Except at very cold temperatures near absolute zero, all conductors have some resistance. It is the principal tool for controlling current.

Strictly speaking, current is negatively charged electrons moving from a comparatively more negative place to a more positive one. But for convenience, it is often easier to think of current as positive charges flowing from positive to negative. This is called the **positive current convention**. It is not entirely fictional, as a positive charge can consist of a space where an electron would normally be.

## OHM'S LAW

Voltage, current and resistance interact in a very common-sense way. Suppose we have an existing circuit, with a certain amount of voltage pushing a certain amount of current through a certain amount of resistance. If we raise the voltage – if we push harder – we should expect the current to increase, and it does. If we raise the resistance, we should expect the current to decrease, and it does.




Since electricity is invisible, I like to make comparisons with a water system. A continuous voltage source, like a battery or generator, could be compared to a pump that creates water pressure. A resistance would be like a tube with sand in it, interfering with the flow of water. That flow, of course, would be the current.

It's time to start working with actual numbers. *How much* does current increase or decrease when we change the voltage or resistance? Well, we're lucky. It turns out that these are simple linear relationships.

Voltage and current are *directly* proportional. Doubling the voltage doubles the current, tripling the voltage triples the current, and so on.

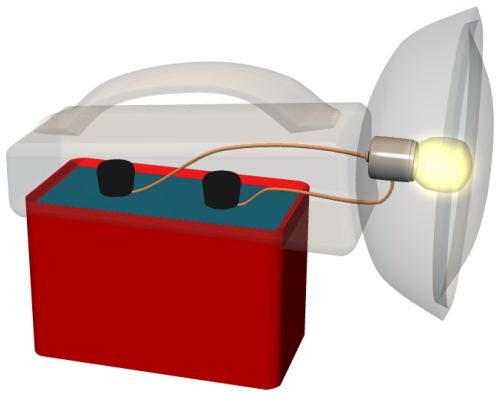
Resistance and current are *inversely* proportional. Doubling the resistance results in half the current, tripling the resistance results in one-third the current, and so on.

A clever person might suspect that these relationships could be combined in a simple equation. That clever person was Georg Ohm, who in 1827 published what has come to be known as **Ohm's Law**:

$$I=V/R$$

In plain English, current (in amps) is equal to voltage (in volts) divided by resistance (in ohms).

So: if you have a 6V battery and a 50Ω incandescent light bulb, how much current will flow when you connect them together? Divide voltage by resistance:



**6/50 = .12 = 120mA**

**For an electronic tech, Ohm' Law is the key to the castle. It is the most fundamental and most frequently used application of the algebra we studied in chapter 2.** With Ohm's Law, we can find the current whenever we know the voltage and resistance. Better yet, we can *control* the current by *choosing* the voltage and resistance.

But suppose we already know the voltage and current, and want to find the resistance? Well, let's call up that algebra stuff you learned in the last chapter. With a little algebra, we can rearrange the Ohm's Law equation into two new equations.

**I = V/R** When you know voltage and resistance and want to find current.

**R = V/I** When you know voltage and current and want to find the resistance

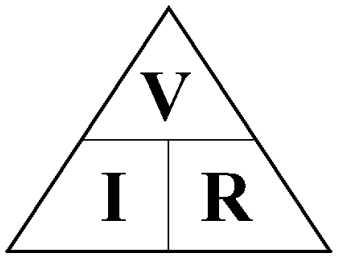
**V = I x R** When you know current and resistance and want to find voltage

These are all the same equation. If you're not yet good at algebra, you should get out a paper and pencil and move the quantities around so you see how the three versions of Ohm's Law are derived from each other. These are the same calculations you will use with actual numbers.

## OHM'S LAW MEMORY AID

Techs discovered long ago that you can't rely on your memory to get the right quantities into the right equations in the right places. Instead, they invented a visual aid.

It's a triangle (or circle, if you like that better) with current and resistance next to each other on the bottom, and voltage on top. That's the critical thing to remember: *voltage on top*.



Ohm's Law Memory Aid

The physical arrangement suggests the three equations. Current and resistance are next to each other, indicating that you multiply them to find voltage. Voltage is above current, like a division problem, indicating that you divide voltage by current to find resistance. Voltage is above resistance, indicating that you divide voltage by resistance to find current.

Until you've got this down cold, it will probably be useful to print this out (a copy is in the Review chapter) or draw it on paper and keep it handy. Then, whenever you want to find one of the three quantities, put your finger over that letter and it will be obvious what to do with the other two. If you just remember to put voltage on top, you can hardly go wrong. Even techs with decades of experience occasionally have to call up this diagram in their minds to remember the equations.

Ohm's Law exercises

1.Suppose a halogen headlight draws 8 amps of current. Assume the battery voltage is 12V. What is the resistance of the lamp filament?

2.Suppose you connect an 18-ohm resistor across a 45-volt supply. How much current will it draw?

3.How much voltage does it take to cause a 5mA current to flow through a 1.2kΩ resistor?

Answers:

$$12V/8A = 1.5\Omega$$
$$45V/18\Omega = 2.5A$$
$$5x10^{-3}A \times 1.2x10^{3}\Omega = 6V$$

Don't stop there. Make up exercises of your own until you can do Ohm's Law in your sleep. The best exercises are scenarios: “If I have a 12-volt car battery and I want this much current to flow...” That way you will be more at ease when you start using these equations in the real world.

## POWER AND WATT'S LAW

There's a fourth fundamental property, Power, that we have put off dealing with because it consists of two of the first three, voltage and current.

**Power** is represented in equations by the letter "**P**." It is measured in Watts, abbreviated "**W**."

Power is what gets things done. It is work, heat, light, motion, radiation. In electronics, we routinely handle and process signals that are, for all practical purposes, only voltage or current – but in most cases, somewhere in the circuit they have to end up as power to do something useful.

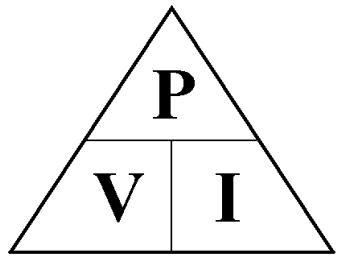
Specifically, **power is voltage times current**. This is **Watt's Law**. Like Ohm's Law, it can be written three ways:

$\mathbf{P = V \times I}$ When you know voltage and current and want to find power

$\mathbf{V = P / I}$ When you know power and current and want to find voltage

$\mathbf{I = P / V}$ When you know power and voltage and want to find current

And, as before, there's a triangular memory aid. This time, the thing you have to remember is that power goes on top. By now you know the drill, so we can go straight to the exercises.



Watt's Law Memory Aid

### Power exercises

1.How much current flows through a 60-watt lamp screwed into a 120-volt socket?

2.If a car heater fan draws 6 amps and we assume the battery voltage is 12V, how much power is the fan motor consuming?

3.If a circuit is consuming 0.1 Watt of power and the current flow is 4mA, what voltage is the circuit connected to?

Answers:

$\mathbf{60W / 120V = 0.5A}$

$\mathbf{6A \times 12V = 72W}$

$\mathbf{10^{-1}W / 4 \times 10^{-3}A = 25V}$

The last one's a little tricky. Let's make it a real fraction by rearranging it so:

$$\frac{10^{-1}\text{W}}{4 \times 10^{-3}\text{A}}$$

Next, let's combine the exponents by multiplying both sides by $10^3$. Remember, you multiply exponents by adding.

$$\frac{10^{-1}\text{W}\ (10^3)}{4 \times 10^{-3}\text{A}\ (10^3)}$$

In the denominator, the "3" and "-3" exponents cancel, leaving us with

$$\frac{10^2\text{W}}{4\text{A}}$$

$10^2$ watts is 100 watts, and 100W divided by 4A is 25V.

## POWER AND RESISTANCE

The equations up to this point have taken advantage of the fact that, if you know two of the quantities involved, you can find the third. But none of the power equations contain an "R." What do you do if you only know voltage and resistance, or current and resistance, or power and resistance? You perform two calculations.

Suppose we only know voltage and resistance, and we want to find power. We could first find the current: $\mathbf{I = V/R}$. Then we could multiply the voltage we started with by the current we've found, and that would give us power. This is a perfectly proper method.

But there's another way. Remember that any of the fundamental properties – voltage, current, resistance – can be expressed in terms of the other two. That means any place an "**R**" crops up, we can write "**V/I**" instead. As you recall from the previous chapter, this is called "substitution" and it's something you do all the time in algebra.

Let's look at the equation

$$\mathbf{P = V \times I}$$

Suppose we don't know **I**, but we know both **V** and **R**. So we change the equation to

$$\mathbf{P = V \times V/R}$$

which is the same as

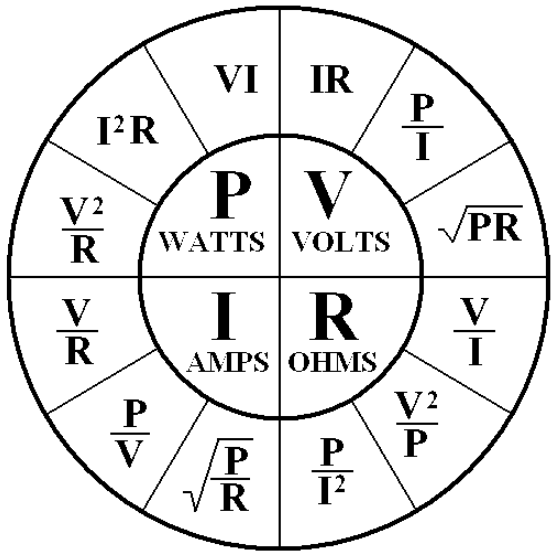
$$P = V^2/R$$

Plug the voltage into the calculator, square it (hit x, then =), then divide by R. The answer you get is the power.

To the right is a graphic that combines the Ohm' Law formulas with power formulas, but it can't be called a memory aid because it's more than most people can reliably memorize. Each quantity in the center is equal to the three adjacent quantities around the periphery; e.g. **V = P/I** or **IR** or $\mathbf{PR^{0.5}}$. This graphic is also in the Review chapter; print it out, keep it with you. This gives you a dozen formulas that take care of any combination of power, voltage, current and resistance. Sometime when you're bored out of your mind, take every one of those formulas and convert them into every other one to practice your algebra skills and lock in the Ohm's Law concepts.

## VOLTGE DROP

Ohm's law has an important implication: since even the heaviest wire has some resistance, any time current flows through it, a voltage will appear between its ends. Thus the voltage delivered to the load will be lower than the voltage supplied by the source. This is **voltage drop**, and it




Ohm's & Watt's Laws

happens whether we like it or not. This is a major headache with a nation's AC power system, where a generating station may be hundreds of miles from the city it powers. Voltage drop in the wire, times current flowing through it, represents power lost. The problem of getting lots of power from one point to another without losing most of it in the wire is one of the main things standing in the way of emerging technologies like wind energy and electric cars.

But inside any piece of electronic equipment, there are likely to be dozens or hundreds of points where we *want* a voltage that is different from the DC supply voltage. We get those, for the most part, by inserting resistors to generate deliberate voltage drops. A large part of the equipment designer's job involves calculating those resistors. A significant part of a service tech's job involves checking voltage drops against resistance, to find the part of the circuit that isn't operating properly.

## RESISTANCE, HEAT AND EFFICIENCY

Any time you have a resistor with voltage across it, you'll have current through it, and thus power. For example, **1V** will push **1A** through a **1Ω** resistor, resulting in a power of **1W**. But where does that power exist, and where does it go? It exists in the resistor, and it turns into heat which **dissipates** into the environment.

Power can take other forms – light, motion, radio waves etc. Generally, the conversion from electrical power to some other form of energy is not 100% efficient. Some of it always turns into heat. 1,000W into a motor, for example, may result in 850W of rotational power and 150W of heat. We would say this motor is 85% efficient. Incandescent lamps, as you probably know, have very poor efficiency; maybe 5% of the input power turns into light and the other 95% turns into heat. Power just loves to turn into heat, and engineers have to work hard to counteract that tendency. On the other hand, where heat is what you want, the conversion is as easy as falling off the wagon.

## CONDUCTANCE

If a glass of water is $^{2}/_{3}$ full, you could also say it's $^{1}/_{3}$ empty. If it's 90% full, it's 10% empty and so on.

Likewise, if something opposes current flow to some extent, that means it also permits current flow to some extent. The degree to which it opposes current is called “resistance” and the degree to which it allows current is called **conductance**. And, since they are opposite sides of the same coin, the traditional unit of conductance is the **Mho**, which is “Ohm” backwards. Oh, how clever. Increasingly, “Mho” is being replaced by the international unit “**S**,” to honor Werner von **Siemens**, German inventor and industrialist and founder of the still-prominent Siemens A.G. company.

Mathematically, resistance and conductance are complements. A 400-ohm resistor has 1/400 mho, which is 2.5 milli-mho or 2.5mS of conductance. (Personally, I don't like “mS,” which is too easy to misinterpret as “millisecond.” Call me an old fogy, but I'm sticking with mhos.)

Gee whiz, 9 pages and we're almost done with Ohm's Law! After 37 pages of math, can this really be the most important thing a tech will ever learn? Absolutely.

Ohm's Law calculations with one resistance are easy. With a bunch of resistances, things get more involved, as chapters 6, 7 and 8 will demonstrate.

Before you take the practice exam, here are some exercises to see if you've got the hang of it.

1. A 12-ohm resistor is connected across a 12V battery. What is the current flow? (Yeah, I'm starting you out easy.)
2. Current flow through a particular incandescent lamp is 0.7A. The resistance of the filament is 40 ohms. Calculate the voltage.
3. An extension cord is plugged into a 120V outlet. (Ok, that's AC, doesn't make a difference.) An appliance is plugged into the other end that draws 10 amps. There's enough voltage drop in the cord that only 115V gets to the appliance. Calculate the cord's resistance.
4. The electric rear window defroster in a car draws 100 watts. Assume the battery voltage is 12V. Calculate current and resistance to 2 places.
5. You are choosing a fuse to protect an 8-ohm, 50-watt speaker. Speakers are rated in watts, but fuses are rated in amps.What current rating should the fuse be?

Answers:

1. I =V/R = 12/12 The answer is1A.
2. V = IR = 0.7 x 40 The answer is 28 volts.
3. $V_{DROP}$ = 5V, I=10A. R = V/I = 5/10 = 0.5 Ohm.
4. I = P/V = 100/12 = 8.33...
R= V/I = 12/8.33... = 1.44... Ω, truncate to 1.4Ω
5. I = $(P/R)^{0.5}$ = $(50/8)^{0.5}$ = $6.25^{0.5}$ = 2.5A fuse. However, as we will see in the next chapter, current ratings for fuses are approximate, so to err on the safe side, a 2.25A fuse would probably be a better choice.

Did you get them all right? Have you reviewed the ones you got wrong? Then you're ready to take the practice quiz.

***End of Chapter 4***

# EM1 Chapter 5
# COMPONENTS

**by Karl Eilers**

*Objectives of this chapter:*

*When you have completed this chapter, you will be able to name types and describe the uses of:*

- *Conductors*
- *Insulators*
- *Semiconductors*
- *Switches and Relays*
- *Buzzers and Bells*
- *Fuses and Circuit Breakers*
- *Resistors, Rheostats and Potentiometers*

Electronic components come in such variety that trying to list all of them would be like trying to name all the people who eat hamburgers. In this chapter, we're going to talk only about the ones most commonly found in DC circuits. There are also components that are found only in AC circuits, which we will study in EM2.

As we saw in chapter 1, there are essentially three kinds of materials in the world: those that readily conduct electricity, those that don't, and those whose conductivity is conditional and controllable. These are **conductors**, **insulators** and **semiconductors** respectively. We're going to look first at these materials, and then at the electronic gizmos that are made from them.

## CONDUCTORS

As we saw in chapter 1, conductors are materials through which electricity flows easily. All metals, and some other materials, are conductors. These are materials with enough shared electrons in their outer atomic shells to permit some of those electrons to travel around.

The most important characteristics of any conductor used in electronics are:

- its resistance
- its ductility (whether it can be bent without breaking)
- its shape memory (whether it springs back, once bent)
- how readily it oxidizes (reacts with oxygen)
- whether it can be soldered
- its weight
- its tensile (stretching) strength
- its cost

## Conductors Used For Wires

At normal temperatures, all conductors have some resistance. The best conductors, those with the least resistance, are used for what you'd expect them to be used for: moving electricity from one place to another.

**Silver** has the least resistance, making it the best conductor. However, it is very expensive, and so only used in small quantities, when the absolute least resistance is required. When soldering, the use of silver-bearing solder is recommended to prevent what you're soldering from being dissolved by the solder.

**Copper** is next best, and it's much less expensive, so it's by far the most-used conductor. Another advantage is that copper is easy to solder. When you deal with wires and printed circuit board traces, you will almost always be dealing with copper. If copper didn't exist, electronics wouldn't be what it is. In these study guides, when we talk about “wire” we're always talking about copper unless otherwise specified.

Copper oxidizes slowly. It should be a bright reddish color; if it's a darker bronze, it has developed an oxide layer. This should be scraped off before the wire is connected. A wire with an oxide layer cannot be soldered.

**Aluminum** has about 60% more resistance than copper. This means, to safely carry the same current, the wire must have 60% more cross-sectional area; which is to say you have to use 60% more of it to do the same job. However, aluminum is so much cheaper than copper that, even though you have to use more of it, it's still less expensive per Ampere than copper.

Aluminum's tensile strength, which determines how hard you can pull on it without stretching or snapping it, is quite a bit lower than that of copper. Even when you take into account the larger diameter of electrically equivalent aluminum wire, the tensile strength is a little lower. But aluminum is so much lighter than copper (about half the weight for an electrically equivalent wire) that it's actually better than copper for long suspended spans.

Aluminum presents several challenges. It cannot normally be soldered. Because of its softness, if it is clamped hard, it can “ooze” over time (called **cold creep**). If this clamping point is an electrical connection, it will become loose, leading to a poor connection, heating, and possibly a fire. For this reason, and because aluminum can oxidize, aluminum wiring is only installed by people specially trained to work with it, and only with special connectors. In most jurisdictions it is illegal for residential wiring.

## Conductors Used In Electronic Components

Most metals are not used primarily for moving electricity over long distances, either because they have too much resistance or for other reasons. But these metals are used in small quantities, transporting electricity over short distances, where their higher resistance doesn't cause unacceptable power loss. They are used for the special properties they possess.

**Brass** is an alloy of copper and zinc. If you bend copper it stays bent. That isn't good for switch contacts or the metal pieces that support them. We want those to be springy, so they'll return to their original position. Brass is springier than either of the metals it's made from. It is also easy to solder.

**Tin** is very ductile and not much good by itself, but it's widely used as a plating over other metals because it is slow to tarnish. Wire is often **tinned** in this manner. It's also a component in solder, which means solder easily forms a good bond with a tinned wire.

**Iron** is the dumb jock of conductors. It isn't that good a conductor, but it's strong and cheap. The short wires attached to transistors (called **leads**, pronounced “leeds,” as in the wires that “lead” electricity to and from a component) are usually iron, plated with gold or tin so they won't rust, and so they can more easily be soldered. By the time they're installed in a circuit, they're only a fraction of an inch long, so their resistance isn't much of a problem.

**Steel** is a jock with some education; it is high-carbon iron, it is never used for contacts or leads but is a popular equipment frame and chassis material because of its strength, ductility and low cost. It can be soldered to, but screw or rivet connections are more common. “High-carbon” steel is very hard, not ductile, and not used as a conductor.

**Stainless Steel** is a jock in a tux. It isn't that good a conductor, but it's plenty good enough when used for the chassis of a piece of equipment. It often contains very little iron, and it's almost nonmagnetic. Medical and food-preparation equipment uses stainless steel for enclosures, where it provides an electrically conductive enclosure and a surface that doesn't tarnish and is easily sterilized. Very high-dollar electronic equipment sometimes comes in a stainless case. It usually cannot be soldered.

**Lead** is the dumb couch potato. It's not that good a conductor and it's soft. Traditional solder used in electronics is a tin/lead alloy that melts at a lower temperature than either tin or lead. This use is declining, as environmental regulations are forcing a transition to lead-free solder. Lead is also the electrode material in car batteries.

**Zinc** is the minimum-wage worker. It doesn't have any standout properties except low cost. It's reasonably hard and conducts well enough for a lot of things. It's easy to melt and cast, so it's widely used for connector shells and the like, usually with a nickel plating. It has almost no ductility; try to bend it and it will crumble. It can easily be soldered, but if it's old, it should be polished up first to remove any oxide.

**Gold** is the artsy wimp. Its great virtue is that it never tarnishes. Tarnish is oxidation of a metal surface, and most metal oxides are non-conductive. Gold switch contacts are popular because they remain good, non-tarnishing contacts for a long time. Switches that handle fragile signals often have gold contacts. It is so soft that, if pure gold were used for contacts, they would quickly be mashed out of shape. It must be alloyed with some other metal to harden it a bit. That's why jewelry is almost never pure gold; it wouldn't last.

**Platinum** is the virtuoso artist. It has gold's no-tarnish property, plus hardness. You'd think it would be preferred over gold, but its hardness makes it difficult to work with. It's also more expensive when you take manufacturing costs into account. There are a number of related “Platinoid” metals, like **Palladium**, that can be used for the same purposes.

**Chromium**, platinum's glitzy twin brother, isn't used by itself in electrical circuits because there are better metals. However, it's a component in “nichrome” wire, which is a high-resistance, high-temperature wire used for space heaters etc. It's also a component in stainless steel.

**Nickel** is platinum's poor cousin. It's hard and shiny and much cheaper than platinum. It can tarnish under some conditions, but doesn't make a habit of it. It's widely used in connectors, as a plating over copper or zinc, and it is easily soldered.

**Bronze**, an alloy of copper and tin and often other materials, is usually found in electronics in the form of **phosphor-bronze**, which has an interesting characteristic. It's “shape memory” is almost perfect up to a point. Like any metal, if you bend it too far, it reaches a critical point where it will not spring back. But up to that limit, it will return almost perfectly to its original shape. It's also hard and not very expensive. This makes it popular for the springy parts of switches and relays. A piece of some other metal is usually attached to the p-b to serve as the actual contact, because p-b rapidly develops a non-conductive oxide. It can be soldered, but if it is not done carefully, the connection will eventually fail. It has a kind of brick-red color; if you see terminals like that sticking out the back of a switch, take a bit of sandpaper or a fingernail file and rough them up just before soldering to make sure there's a clean surface. Better yet, use push-on crimp connectors.

**Beryllium** is another metal with good shape memory. It's used in higher-quality switches and other components. Beryllium shavings, if inhaled, can cause granulomas in the lungs.

## POOR CONDUCTORS

Next comes a group of materials that are conductors, but not very good ones. They are far from useless; we depend on materials with high resistance to control current in electronic circuits.

**Carbon** and various carbon compounds are used in resistors, which we will study below. Carbon is a bulk material that resists electricity as sand resists the flow of water.

Carbon has a slippery quality that makes it useful as a lubricant – graphite is basically carbon. In electricity, it is used where current must be delivered via a contact that slides on another part. Where this happens constantly, as in a motor or generator, the part has to be lubricated or it will destroy itself. The problem is, most lubricants are insulators. But a sliding contact made of a hard carbon-based material can deliver power and self-lubricate at the same time. Carbon contacts are made with a large surface area to compensate for their high resistance.

A liquid compound containing carbon can be made that forms a hard film when it dries. This is used in precision resistors among other applications. Carbon is also mixed with plastic and rubber foam to create conductive shipping and storage containers for static-sensitive parts.

**Tungsten** replaced carbon as the material of choice for incandescent lamp filaments. Its great virtue is that it's one of the few conductors that can glow white-hot (around 4,000 degrees F) without disintegrating. Its drawback is that it's so hard and brittle that it took many years for engineers to learn how to make lamp filaments out of it.

**Nickel-chromium** or **nichrome** is the ideal alloy for space heaters, electric stoves and the like. It's also used in large resistors because, as you know by now, when current flows through a resistance, the result is heat – often a lot of it. Nichrome is hard, it has high resistance for a metal, and it can get orange-hot before it melts.

There are a number of alloys similar to nichrome that may be preferred in some applications. Resistors often use a metal film of one kind or another instead of the bulk carbon or carbon film that might otherwise be used.

Resistance metals like these can usually be soldered – in some cases special kinds of solder are required – but solder can't be used if the material will get hot enough in normal use to melt the solder connections. In space heaters, for example, the heating elements must be connected via screws, rivets, welds or push-on connectors.

## INSULATORS

Insulators are the opposite of conductors: electricity normally does not flow through them at all.

Every insulator has a voltage breakdown limit, which is different for different materials. For example, dry air is an insulator, but at about 10,000 volts per inch of air, its insulating limit is exceeded and a spark jumps. The maximum voltage per unit of thickness is often called the **dielectric constant.**

If we need conductors to move electricity around, we also need insulators to keep it from going where it shouldn't. Early researchers couldn't get electricity to flow from one end of a wire to the other. Eventually they realized that it was draining off at every point where the wire was supported, and they needed to use insulators at those points. The bumpy tubes you see supporting the wires on electrical poles are the modern versions of those insulators.

Today, of course, we routinely encase the entire length of a wire in insulation, which allows us to handle it, run it through walls, wind it into coils and so on. Then, when we get the electricity where we want it, we strip a little insulation off the end of the wire so we'll have access to the conductor. But we still use insulating objects when we string high-voltage wires through the air, and inside equipment where we want to attach something to a metal frame physically but not electrically. Elements with outer electron shells almost full tend to be insulators. Also, many elements that are conductors become insulators when they combine with other elements to form molecules, the shared electrons completing the outer orbits of all the atoms.

Most objects are insulators. Look around; you will discover that almost everything in your field of vision is an insulator.

Some of the important characteristics of an insulator are:

- its dielectric constant – how much voltage an insulator can withstand, per unit of thickness
- its flexibility, bendability, hardness
- its melting temperature
- whether it is fireproof and/or emits toxic gases in the presence of flame
- its optical transparency
- issues involved in its manufacture

**Rubber and Plastic** are probably the most-used insulators. Virtually all wire insulation these days is plastic, or where great flexibility is required, rubber. I'm not even going to try to list the variety of plastics that are used. Some, like Teflon, find special application in public buildings, which require wire insulation that does not burn or emit toxic fumes in a fire. Others have especially high abrasion resistance. Plastic is so often made to imitate other materials that we hardly realize how much of the stuff around us is plastic. Chances are, your elbows are sitting on a plastic surface.

**Varnish and cloth** were used before adequate plastics were developed. Solid, insulated wire used in electromagnets (**magnet wire**) is still called “varnished” wire occasionally, but the insulation is actually plastic. Some countries still require cords on irons and other heat-creating appliances to be cloth insulated.

**Glass** is a very high quality insulator where rigid support is required. It's one of the few insulators that's transparent.

**Ceramics** include a wide range of manufactured materials that are similar to glass in hardness, but less breakable. Also, glass can melt if the temperature gets high enough. There is no situation normally encountered in electronics that will melt a ceramic material. The conductors will melt first.

**Dry wood** is an insulator, but not to be trusted around dangerous voltages, because wood becomes something of a conductor when wet. Early experimenters in radio laid out their circuits by putting screws and nails into wooden breadboards and attaching components to them. There isn't much reason to use wood in electronics today.

**Paper** is processed wood, once widely used when an entire surface had to be insulated, now largely supplanted by plastics.

**Phenolic materials** are widely used for inexpensive printed circuit boards. Most consumer-grade electronic equipment uses some variation of phenolic printed circuits, which is something to keep in mind if you wind up servicing consumer equipment, because phenolic PC boards can easily be cracked. They're made of thick paper infused with a phenolic resin. Phenolic PC boards are not fireproof and, if they carry hot components, will eventually char and crumble. This is not as big an issue as it was during the vacuum-tube days, as most modern circuitry runs cool.

**Epoxy-filled fiberglass** is used for high-quality printed circuit boards, especially around high temperatures, or where they get a lot of banging around and need to be tough.

**Mica** is an excellent insulator with superior dielectric properties. In its natural form, it is found in thin sheets. Because of its stability in extreme high-temperature situations, it is one of the best natural mounting materials for heating elements in space heaters, soldering irons and the like. It's fairly easily cracked, so it isn't good for supporting heavy parts.

**Quartz** is naturally found in crystal form; it can also be melted and either formed into crystals, or if other chemicals are added, made into a superior high-temperature glass. When in crystal form, it has an interesting property: if you attach an electrical potential across it, it will bend slightly. Conversely, if you strike it, causing a momentary deformation, it will produce an electrical potential. Trigger-type butane lighters operate by striking a quartz crystal to generate a spark. This is called the **piezoelectric** (pee-AY-zo) effect. In EM2 we will see how this is put to use in electronics.

**Water** is an insulator, believe it or not, as long as it's pure water. Of course, most water has minerals and stuff in it, and then it becomes a conductor – a poor one, but good enough to kill a careless tech working in a damp basement.

## SEMICONDUCTORS

Between insulators and conductors, chemically, there are some materials that are kind of quirky. Their outer electron shells are about half full. These are the semiconductors, and they can be anything from good insulators to reasonably good conductors depending on whether they are pure or contain certain impurities. They can be made to conduct electricity in one direction only, or to switch on and off, or to conduct just so much and no more. There are also chemical compounds that are semiconductors.

Most semiconductors naturally take the form of crystals. If you've ever taken sugar and water and made rock candy, you have a pretty good idea how manufacturers take hot semiconductor soup and create the orderly shapes that become transistors, integrated circuits and so on.

Semiconductors have given us tools far beyond what old-time techs could ever have imagined. We cannot control the properties of conductors and insulators; they just do what they do, and our options are limited to choosing the best ones for particular applications. But semiconductors do what we tell them to do, within limits, and those limits are being pushed back every day. Semiconductor circuits so small a microscope cannot see them can control battleships. Per unit of weight, they are worth far more than gold.

**Selenium** was once used for rectifiers, which are electrical one-way valves. It had a nasty habit of burning up, and smelling like a dead animal when it did so.

**Germanium** is the material first used in transistors. The early transistor industry was built on germanium, but it isn't used very much today because silicon is better in almost every way.

**Silicon** is the nearly-universal semiconductor material today. Virtually all transistors and integrated circuits are made of it. Silicon supplanted germanium because it can withstand higher temperatures without melting. It is also easier to obtain certain electronic properties with silicon. An old selenium rectifier the size of a shoe box can be the size of a plastic bottle cap with germanium and a pencil eraser with silicon. The only reason to make a semiconductor device from anything other than silicon is to take advantage of a special material characteristic for a special application. The alloy **silicon carbide** is beginning to emerge as a very high-temperature alternative in high-power applications.

**Galium-arsenide** and a number of other compounds are used for special purposes, notably light-emitting diodes. Certain exotic semiconductor materials work at higher frequencies than silicon.

**Carbon** could be called a semiconductor, but it would be more accurate to just call it a relatively poor conductor. You can't make transistors out of it. However, very thin carbon films, called **graphenes**, promise to give us a whole new class of semiconductors. Good thing, too, because it's hard to get silicon to work at frequencies above 4GHz, and cellphones are already up to 2.7GHz. Graphenes can work to 10GHz and beyond. Just now, in 2011, researchers have built the first graphene integrated circuits. Keep an eye on this one.

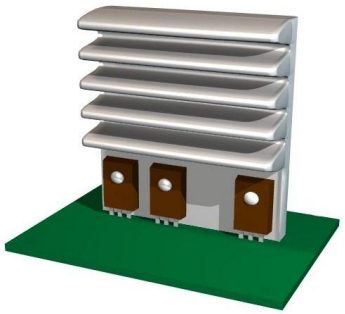
There are so many kinds of semiconductor devices that, rather than discuss them in this chapter, I've given them whole chapters of their own.

## THERMAL CONDUCTIVITY

Anything that's good at conducting electricity is probably good at conducting heat. That's important, because any time there is a voltage drop and current, electricity is being turned into heat, and a lot of that goes on in electronics. If you make heat and don't get rid of it, the temperature rises until the equipment destroys itself.

One way of getting rid of heat is to transfer it to the air, via convection or radiation or both. But in many cases, a lot of heat is created in a very small area deep inside a piece of equipment, far from the air.

The job of a heat conductor is to move the heat from its origin and spread it out so the air can take it away. When used this way, the heat conductor is called a **heat sink**. Most heat sinks are aluminum; a few are copper.



Anything that insulates electricity probably also insulates heat. Wood is still used for things like frying pan handles, but isn't much used in electronics any more. Plastics, ceramics, glass and similar materials are used to keep hot things separated from things that don't like being hot. But the easiest and cheapest way to keep hot things from transferring heat to other things is to space them apart. Air is a pretty good heat insulator.

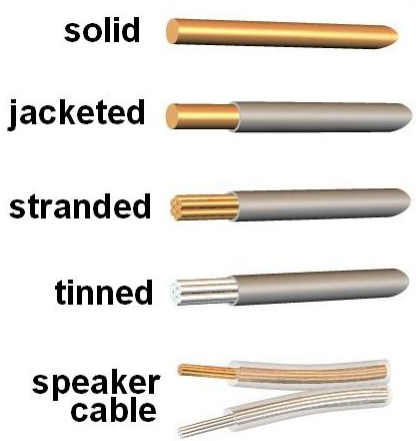
## ELECTRONIC COMPONENTS

Now that we've looked at materials and their properties, let's start talking about the things that can be made with them.

## WIRE

As previously mentioned, throughout these study guides, we will assume that wire is always copper. People who work with different materials get special training for it.

Where DC is concerned, there are few electrical differences among different kinds of copper wire. However, there are physical differences.




● The wire may be bare or, much more often, have an insulating **jacket.** Usually, the jacket is PVC or a similar plastic. Special plastics, like Teflon, are used in public buildings because they don't melt or give off noxious fumes in case of a fire. In other cases, a special plastic may be chosen for its abrasion resistance. Rubber insulation is used where a wire will experience a lot of flexing. When we want to make a connection to a wire, we strip the insulation off a small length at each end of the wire.

● The wire may be copper alone, or it may be **tinned** (given a tin coating) to make it easier to solder.

● The wire may be **solid** – in one piece – or **stranded** – a bundle of fine wires. Solid wire is fine for most purposes but, as you probably know, if you bend a piece of metal back and forth a lot, it will eventually break. In an electrical circuit, that can be a very dangerous thing. Stranded wire can take much more flexing without breaking Also, it's physically easier to flex, which is one reason why cables for guitars, microphones in cabs and police cars, computer mice etc. use stranded wire. Rubber-jacketed wire is almost always stranded, because the main reason for using rubber in the first place is to accommodate flexing. Electrical codes require that machinery be connected via stranded, rubber-jacketed wire due to the vibration that can be expected; solid wire could fatigue and break.

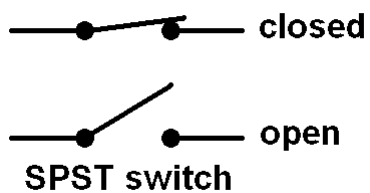
● Several wires may be bundled in a common jacket. This is called a **cable.** These wires are often twisted around each other which, as we will see in EM2, can be an effective way to prevent the cable from radiating or picking up interference.

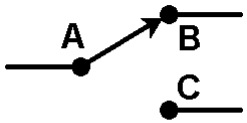
## SWITCHES

Physically, there are a gazillion kinds of switches, but electrically, they all do the same thing – create and break circuits. When a switch creates a circuit, we say it **makes**, as in making or completing a circuit, or it **closes**. The switch is then **closed**. When a switch breaks a circuit, we say it **breaks** or **opens** and it is then an **open** switch. Below are some of the details that matter to a tech.

**Voltage and current being switched.** You can't use a switch intended for switching tiny data signals to switch a big motor on and off, obviously. You *can* use a big-motor switch to switch data, but it might not be reliable; big switches depend on that high current to keep their contacts clean. The switch should fit the application.

**Number of active positions.** The simplest switch has two terminals, and the handle has two positions. In one position, the terminals are connected – the switch is "closed" - and in the other position, the terminals are not connected – the switch is "open." This is called a **single throw** switch. Yes, you can "throw" the handle two ways, but only one way results in a connection.

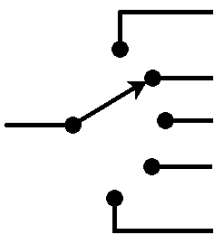




SPDT switch

Some switches have three terminals. In one position, terminal “A” is connected to terminal “B”; in the other position, terminal “A” is connected to terminal “C.” This is called a **double throw** switch because a connection is made in both handle positions. In schematic diagrams, a multiple “throw” switch is usually drawn with an arrow on the moving part.

A switch can have more than two positions, though the word “throw” makes less sense in these cases. The **rotary** switch used as a source selector switch on an old home theater receiver might be an 5-position switch, with one common terminal that can be connected to any of 5 other terminals.

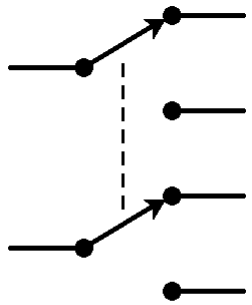

rotary switch

**Number of circuits.** You might want to close or open several circuits at the same time. You could physically gang several switch handles together – think of the dual or triple breakers you often see in power panels – but it's more elegant to build several switches into one case and operate them with one handle.

Each switch circuit is a **pole**. A switch can have as many poles as required by the application. In pipe organs you often find 61-pole switches.

There's a kind of code used to identify switches: number of poles first, then number of throws. **SPST** means single pole, single throw. **SPDT** means single pole, double throw. **DPST** means double pole, single throw. **DPDT** means – do I have to tell you? – double pole, double throw. After that we use numbers: an 8-pole, 5-position switch would be 8P5T.

The schematic symbol for a multi-pole switch is simply several switches, with the moving part joined by a dashed line. This line indicates that all the poles move at the same time, but are not electrically connected together.


DPDT switch

**Break-before-make or make-before-break.** In some cases, an open circuit cannot be permitted to exist, even for a moment. In these cases, a make-before-break switch is used, where two contacts are both connected to the common contact for part of the handle movement. In other words, they're shorted together.

In other cases, one circuit *must* break before the other makes. For example, if you're using a DPDT to reverse the direction of a motor, a make-before-break switch would short the power line during switching, which would be really exciting, especially after the fire trucks show up.

In this case, and in the majority of cases, a break-before-make switch is called for. A switch can usually be assumed to be **BBM** unless there's a specific reason it has to be **MBB**.

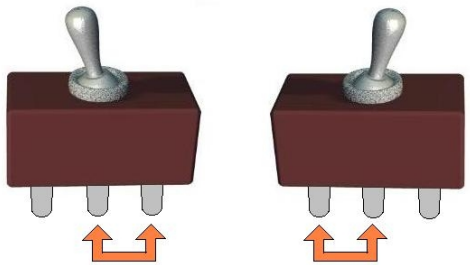
**Snap action.** In the simplest switch design, the position of the contacts corresponds to the position of the handle. This kind of switch is often called a **slide switch**. If the handle is moved very slowly, the contacts open or close very slowly. In many cases, this can lead to sparking and arcing, which is always undesirable and often dangerous.

Where there is enough current to cause arcing – and more so in DC than in AC circuits – snap-action switches should be used. These switches have a trigger mechanism; no matter how slowly you move the handle, they close and open with a snap. Thus no arc can develop as long as the switch is used within its ratings.

When you're switching video or audio signals or data streams, there is no power to speak of and no reason a snap-action switch must be used.

In a **toggle**-handle switch, if the switch has two terminals at one end (single throw), the switch is usually closed when the toggle is *away* from the terminals. The slot identifies the "off" position. With a double-throw switch, the closure will be between the center terminal and the one away from the toggle.

Full-size toggle switches mount in a ½" hole; miniature toggle switches mount in a ¼" hole. Most rotary switches mount in a 3/8" hole, and there's usually another small hole which matches a tab on the switch that keeps it from spinning around.




## PUSHBUTTONS AND MOMENTARY SWITCHES

Most switches can rest in either position, but a **momentary** switch has a **normal** rest position. If you push it to the other position and release it, it will snap back. Most pushbuttons are also momentary.

In these cases, an additional piece of information is necessary: whether a switch is open or closed in its rest position. A doorbell button is **normally open (N.O.)** and closes when you push it. A refrigerator or automotive dome light switch is **normally closed (N.C.)**, that is, it's closed when released.

Of course, it's usually held in the depressed position so the light is normally off. The schematic diagram for a pushbutton is a pair of dots and a cross bar.

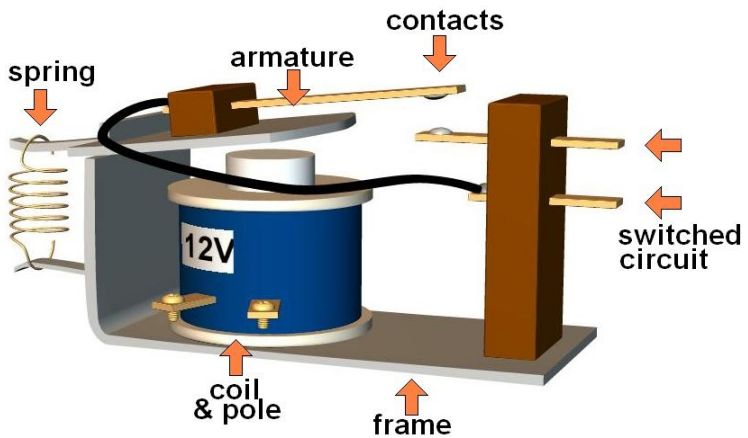
In switch specifications, parentheses are used to indicate a momentary position. A single-throw, normally off momentary switch would be labeled “OFF-(ON).” A momentary double-throw switch, which has closed contacts in both positions, would be labeled “ON-(ON).” A three-position switch which is off in the center, and has a momentary closure in either direction (that is, a double-throw switch that it returns to a center-off position when you release it) would be “(ON)-OFF-(ON).” You'd find that kind of switch on an industrial garage door or electric forklift.

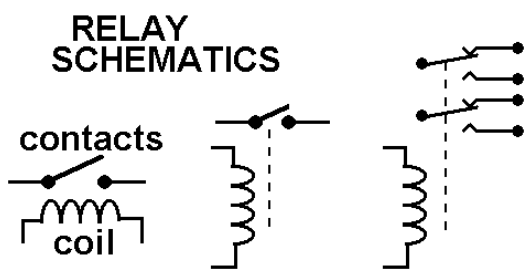
There are also push-on, push-off buttons, like the power button on a computer.

## RELAYS

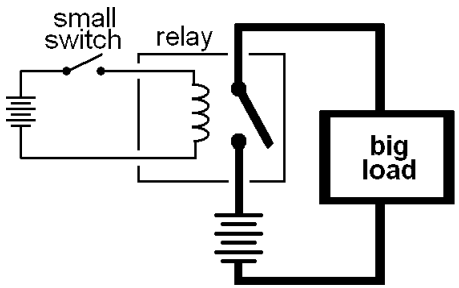
A relay is a set of switch contacts operated by an electromagnet. The electromagnet **coil** is either made to operate on DC or on AC, not both. The stationary iron piece in the middle is called the **pole** and the pivoting piece with the moving **contacts** is called the **armature**. When the magnet is energized, we say that the armature **pulls in**, and the contacts close. When it is de-energized, the **spring** returns the armature to its rest position; we say it **drops out**.

The pull-in and drop-out voltages will be very different. For example, a relay intended to work on 24V will typically pull in when the voltage reaches 16V and, once pulled in, will not drop out until the voltage falls to about 4V.



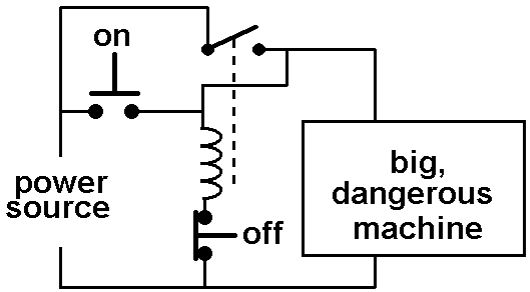
If the relay is operated by a switch, you get a switch operating a switch. What good is that? Well, for one thing, it's a way for a small switch to control a large current or dangerous voltage.



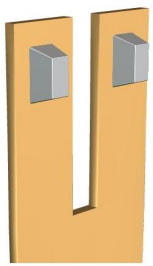

For example, the starter in your car can draw several hundred amps. If the key switch had to handle that kind of current directly, can you imagine how huge it would have to be? So, instead, the key operates a big relay, which might draw one amp, and the relay in turn switches the 100 amps for the starter. This type of relay is usually called a **solenoid**.

The maximum rated contact current will likely be different when switching AC than DC, because DC is more prone to arcing. A relay may switch several poles, and the poles may be of different types, i.e. not all single-throw or double-throw or not all rated for the same current.

A relay can be made to “latch” by wiring its contacts in parallel with a “start” pushbutton, which is normally open. Once the relay armature pulls in and the contacts close, the pushbutton can be released and the relay will stay closed. A normally-closed “stop” button in series with the relay breaks the circuit to unlatch the relay. This circuit is widely used to control machinery because, if power fails, the relay automatically drops out. That way the machinery won't suddenly start up by itself when power is restored.




If it is necessary to prevent the “on” button from momentarily carrying all the current to run the load, a double-pole relay can be used. One set of contacts supplies electricity to the load; the other latches the relay.



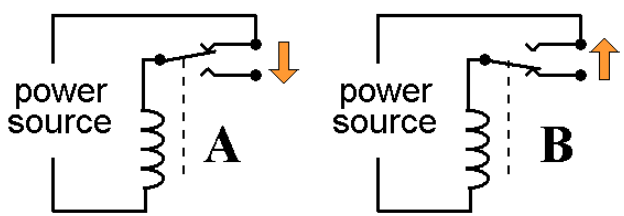
Signal-switching relays often have **bifurcated** contacts, where each contact is forked like a snake's tongue. This is a simple way to improve reliability. For the relay to malfunction, both sets of contacts must fail at the same time, which almost never happens.

Bifurcation isn't used for high-power relays because it would simply mean that whichever contact makes first or breaks last would carry all the load for an instant.

Increasingly, mechanical relays are being replaced by electronic equivalents, which we will study in EM3.

## BUZZERS AND BELLS

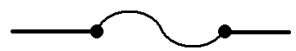
A relay can be wired in such a way that it won't sit still. If it has normally closed contacts, and its coil is wired in series with them, when the armature is out it will be pulled in (A) and when it's pulled in it will drop out (B). In other words, it will go back and forth. This is described as an **astable** condition – long "a" as in "game" – meaning the armature does not have a stable rest position. Something that goes back and forth is also said to **oscillate**.



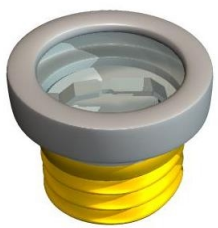

If designed to do so, the armature will slap the pole piece with each oscillation. That's how buzzers are made. We can add a bell, and strike it with a finger attached to the oscillating armature. That's how alarm bells are made.

By the way, as I'm showing you these latching and oscillating circuits, I hope you're not just glancing at them and saying "meh." You should be tracing current flow and thinking about why the circuits work the way they do. That kind of thinking will be a large part of your job as a tech.

## FUSES



A fuse is simply a weak link in the circuit, an undersized wire that melts to open the circuit before any of the other wires get hot enough to be dangerous. The electrical fuse seems to have been invented when the first house Edison wired for electricity caught fire. One of his electricians had accidentally wired a short circuit, and there was no safety device to limit current flow. Edison took the screw base of a regular light bulb and put a small-gauge wire across the contacts, and then screwed the lamp base into a socket and wired it in series with the rest of the circuit. He installed one in every branch of the wiring. The lady of the house still refused to sleep there for years, but this basic plan has been standard for building wiring ever since.

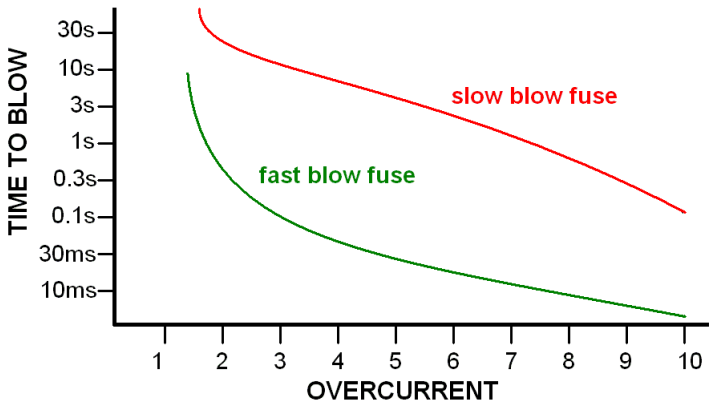


Fuses are rated in Amps, not Volts or Ohms or Watts, because it is current that makes them blow. A 1-amp fuse might blow at a power level of 10 watts or 500 watts, depending on the voltage in the circuit, so the only rating that makes sense is a current rating. This means you have to do a conversion calculation to select the right fuse when the load is rated in Watts.

Electronic equipment fuses are usually glass or ceramic cylinders. The two most used sizes are **3AG**, with ¼" x 1¼" dimensions, and **8AG**, with ¼" x 1" dimensions. These forms were originally designed for automotive use. Ironically, in cars they have largely been replaced by blade-type plastic cased fuses.

Electrically, the main differences among fuses have to do with how long it takes for an overcurrent situation to make them blow. Fuses are broadly divided into **slow blow** and **fast blow** types. A slow blow fuse takes around 20 seconds to blow at twice its rated current, 3 seconds at 5 times its rated current and 0.2 seconds at 10 times its rated current. A fast blow fuse takes only 0.4 seconds at twice its rated current, 30mS at 5 times its rated current and under 10mS at 10 times its rated current. These are very rough estimates with significant variance among manufacturers and fuses.

Either type of fuse will hold indefinitely at its rated current, as long as there's free air movement and the ambient temperature is room temperature. However, this is often not the case. For example, a cartridge-type fuse holder encloses the fuse, preventing ventilation. For this reason, fuses are normally run at no more than 75% of their rated current. On the other hand, if a fuse is protecting a piece of equipment that may be run close to its power limit, the fuse may be deliberately undersized.




Once a fuse is blown, of course, you have to throw it away and put in a new one. I said it in the safety chapter, and I'll say it again here: always use the right type and size of fuse!

The heating permitted by an oversize fuse is proportional to the *square* of the amount of overage, so putting in too large a fuse can be really dangerous – and putting in too small a fuse just guarantees you'll have to replace it again. Your vehicle should have a fuse caddy with, at a minimum, every 3AG and 8AG fuse in every current rating of ½A and above, in both fast and slow blow. Go on, do it, fuses are cheap. Besides, putting in the wrong fuse because you don't have the right one makes you look like a boob in front of the customer.

## Fuse Voltage Rating

A fuse has a maximum voltage rating, usually stamped on the fuse body. Many techs are confused about how this rating should be used in calculating maximum current. The answer is, it isn't used in that calculation. What melts the conductor and blows the fuse is *current*.

What's the voltage rating for, then? If the fuse opens, the entire power supply voltage will appear across it. If the voltage is high enough, it will arc across the melted ends of the fuse's internal conductor. The voltage rating tells you the maximum voltage that will not cause arcing; in other words, the maximum-voltage circuit the fuse can safely be used in.

For example, a 5A, 250V fuse can safely be used in a 5V circuit, or a 24V, 50V, 120V or 220V circuit. It will blow at around 5.5A in any of those circuits. It would also blow at 5.5A in a 400V circuit, but then you might get internal arcing, so it's not safe to use in a 400V circuit.

Another example: automotive fuses are often rated at 32V. You can use a 250V fuse to replace a 32V fuse, but you can't use a 32V fuse to replace a 250V fuse. And of course either one will work fine with a car's 12V supply.

## THERMAL FUSES

Often, there's a “thermal” fuse buried deep inside a component that is made to open not on dangerously high current, but on dangerously high temperature. Window fan motors are one example. These thermal fuses are not accessible or replaceable. This is done on purpose. Once a component has been hot enough to melt the fuse, it's never again safe to use. The fuse is inaccessible so people won't try to re-use the component.

## CIRCUIT BREAKERS

These are much more expensive than fuses, but they have three great advantages. First, in case of excessive current, instead of blowing like a fuse, a breaker just “trips” and you

can reset it. You don't have to buy a new one. In some applications, like the overcurrent protection in an air conditioner, a breaker that automatically resets itself after a cool-down period is used. Second, a breaker's trip point can be much more precise than that of a fuse. Third, a breaker can be made to operate instantaneously. A breaker is used in electronic equipment where an occasional overcurrent condition is a normal occurrence.

Some kinds of equipment have several power sources, and disabling one while others remain active can cause damage. Breakers can be ganged together like multi-pole switches so excessive current through any of them will trip them all. Alternately, the equipment may incorporate monitoring circuits that sense a problem anywhere in the circuit and trip a single breaker at the power input point. Often, a monitoring circuit is designed so that, when it detects a fault, it deliberately throws a hard short across the power supply to trip the breaker. This is called a **crowbar** circuit.

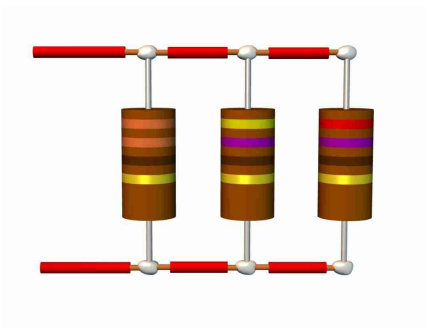
A breaker can operate thermally or magnetically or both. This permits the breaker to have a dual trip characteristic.

With a minor overcurrent condition, a dual-action breaker does not trip unless the overcurrent goes on for a while, like a fuse. With a major overcurrent, the breaker trips within milliseconds. The breakers in building wiring circuits are usually of this type.

Some breakers are reset by pushing a button, others by flipping a lever. In some cases a lever-type breaker is mounted on the front panel of a piece of equipment, and serves as the power switch.

## RESISTORS

A resistor is used where we want a certain amount of resistance lumped together in one place, to control current flow or obtain a voltage drop in a circuit. A piece of electronic equipment typically contains dozens or hundreds of resistors. In most parts of most circuits, the power levels are so low that the heat generated by these resistors is insignificant, but resistors specially made to handle high power levels are available for those cases when they're needed.



**3 RESISTORS IN PARALLEL**

A resistor designed to safely dissipate 5 watts or more is usually called a **power resistor.**

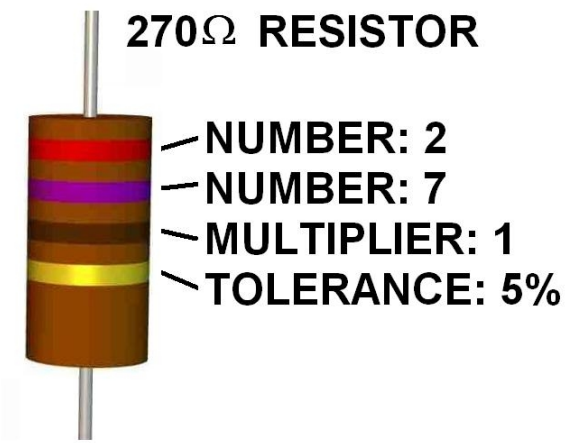
Resistors in electronic equipment are as common as coins in a laundromat. You should get to know all about them.

A traditional resistor takes the form of a cylinder or peanut with a wire lead sticking out each end. Its value is identified by several colored bands going around the resistor. Each band has a specific color which corresponds to a number as follows:

| | |
|---|---|
| **BLACK** | **0** |
| **BROWN** | **1** |
| **RED** | **2** |
| **ORANGE** | **3** |
| **YELLOW** | **4** |
| **GREEN** | **5** |
| **BLUE** | **6** |
| **VIOLET / PURPLE** | **7** |
| **GREY** | **8** |
| **WHITE** | **9** |

Here's how it works: the color bands are bunched up toward one end of the resistor. Reading from that end, the first two bands are numbers, the third band is the number of zeroes that follow the first two. This third band is called the **multiplier**, which is a bit misleading, because you don't multiply the first two numbers by that value. Instead, after the first two numbers you add zeroes, meaning you multiply those two numbers by some power of ten.

Specifically, you add however many zeroes are indicated by the color of the third band: brown means add one zero, red means add two zeroes, and so on. For example, ORANGE, ORANGE, ORANGE means 3, 3, and 3 zeroes – 33,000 Ohms or 33kOhms.




The resistor to the left is 270 ohms - RED, VIOLET, BROWN; 2, 7 and 1 zero.

This color code absolutely should be committed to memory. You're not a real tech until you can look at a resistor and name the value.

A number of memory aids have been developed. Here's the one I like: "**B**etter **B**e **R**ight **O**r **Y**our **G**reat **B**ig **P**lan **G**oes **W**rong" - **B**lack **B**rown, **R**ed, **O**range, **Y**ellow, **G**reen, **B**lue, **P**urple (violet), **G**rey, **W**hite. Some of the others are obscene or abusive. You might think they're funny until you recite one aloud without thinking, in the presence of a customer, forcing your employer to fire you to save face. Stick with the clean one.

So far, the lowest resistor we can identify with this code is 10 ohms, which is BROWN/BLACK/BLACK (1, 0, no zeroes following). To permit lower value resistors, we add gold and silver to the available 3rd-band colors. A gold multiplier band means the value is multiplied by 0.1, to give values between 1 and 9.9 ohms. A silver multiplier band means the value is multiplied by 0.01, to give values between 0.1 and 0.99 ohms.

## Resistor Tolerances

Resistor values are not exact. It is impossible to make them perfect, and if you could, inaccuracies in other parts of the circuit would render the exercise pointless. Instead, resistors have a certain **tolerance**, a certain range above and below their nominal value in which their actual value may fall. Most resistors have a fourth band, and this indicates the tolerance.

If there's no band at all, the resistor has a 20% tolerance; a 1kOhm resistor could be off by 20% or 200 ohms. That is, its value could be anything from 800 to 1200 ohms.

A 20% resistor has to be a really old one. To make a resistor that sloppy with today's technology, they'd have to be trying. Standard resistors today are always within 10%, usually 5%. A **silver** fourth band identifies a 10% resistor; a **gold** band identifies a 5% resistor.

Resistors come in standard value increments. For 10% resistors, these are:

**1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8** and **8.2 Ohms.** (silver 3rd band)

Then the cycle starts over:

**10, 12, 15, 18, 22...** (black third band)

and again:

**100, 120, 150, 180, 220...** (brown third band)

and again:

**1k, 1.2k, 1.5k, 1.8k, 2.2k …** (red third band)

...and so on, up into the tens of megohms. 100 megohms and higher are rare and special resistors.

The reason for these strange numbers is that they're proportional. Each is approximately 20% larger than the last, which means any theoretical value will fall within the + or – 10% tolerance of a standard resistor. There's no point in making these increments any smaller; in-between numbers won't yield better precision if the resistors themselves could be as much as 10% off.

5% resistors have half the tolerance, so as you'd expect there is a standard value between every one of the standard 10% values. When you work with electronic equipment a lot, these values become second nature. In the meantime, there's a chart in the Review chapter that you can print out for reference.

For 5% and 10% resistors, two numbers plus multiplier give us all the accuracy we can use. There is no point in specifying the number to three-place accuracy – 274 ohms for example – when a 5% resistor could be anywhere from 260 to 288 ohms. Today, however, 1% and 2% resistors are as cheap as 5% ones. Tighter tolerances mean more standard values, so now we have to add a third band before the multiplier. So, RED/VIOLET/YELLOW/ORANGE means 2, 2, 4 and 3 zeroes – 274kOhms.

This requires a mental shift. Someone who has the color code well memorized doesn't even have to think to know that an orange third band means the resistor is between 10k and 99k. But with three number bands, the same resistor would have a red multiplier. If you're having trouble grasping that one, take a pencil and paper and work out some resistor values.

To throw a further monkey wrench into the equation, there was a time before all this got sorted out when some manufacturers added the third color band but didn't change the multiplier color. You won't run into this very often, but if you're trying to fix an older piece of equipment, and you're measuring voltages and making calculations and things seem to be off by ten to one, that might be the reason. Take an ohmmeter and check some resistors.

At least one thing makes sense: 1% resistors are identified by a brown tolerance band, and 2% resistors are identified by a red one. The complete chart is on the next page, and a chart you can print out is in the Review chapter.

| COLOR | NUMBER BAND VALUE | NUMBER OF ZEROES | RANGE OF RESISTANCES | TOLERANCE |
|---|---|---|---|---|
| BLACK | 0 | 0 | 10-99 | 1% |
| BROWN | 1 | 1 | 100-990 | 2% |
| RED | 2 | 2 | 1K-9.9K | |
| ORANGE | 3 | 3 | 10K-99K | |
| YELLOW | 4 | 4 | 100K-990K | |
| GREEN | 5 | 5 | 1M-9.9M | |
| BLUE | 6 | 6 | 10M-99M | |
| VIOLET / PURPLE | 7 | 7 | NOT USED | |
| GREY | 8 | | NOT USED | |
| WHITE | 9 | | NOT USED | |
| SILVER | | 0.01X | 1-9.9 | 10% |
| GOLD | | 0.1X | 0.1-9.9 | 5% |

## Temperature Stability

Resistor values are specified at room temperature. Some resistors have yet another band which tells you how much their value drifts when temperature changes.

In most electronic equipment, resistor stability isn't an issue, and any resistor will do as well as any other. If you run into a resistor with a temperature band, you should assume its stability must be important to the circuit it's in, or they wouldn't have used a special resistor. If it needs replacing, it must be replaced by an identical resistor.

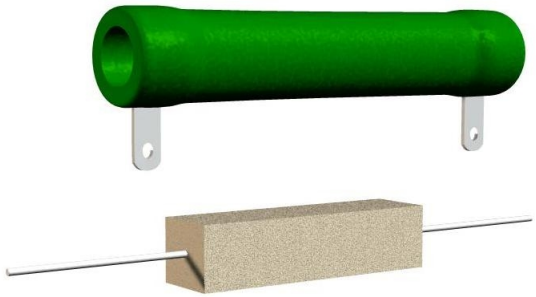
By now we've filled up the whole resistor with color bands. Which end is which? Remember, they'll be bunched up toward one end and that's where you start.

## Resistor Sizes

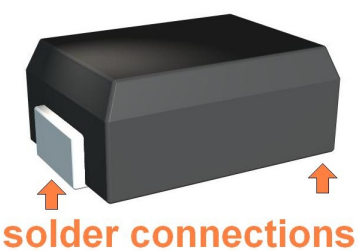
The size of a resistor is related to how much power it needs to be able to dissipate. The standard size for many years was the ½-watt axial-lead resistor. This is a cylinder or peanut shape with a lead coming out either end. For insertion into a PC board, the leads are typically cut short and bent at right angles close to the body. When prepared this way, the resistor leads are typically 0.5” apart.

Nowadays, few resistors have to dissipate anywhere near ½ watt. Most axial-lead resistors today are ¼, $^1/_8$ or $^1/_{10}$-watt, which are just like ½-watt resistors except shorter and narrower.

In the other direction, power resistors can be as large as needed to dissipate the power involved. A 5-watt resistor typically has a case of fused sand or ceramic material, and might be ½" square by 1" long. Inside you'd find a coil of nichrome wire. Electrical utility companies sometimes build resistor banks as large as a barn to burn off excess power during times of low demand. Everybody knows that's wasteful, but you can't throttle a gigawatt power plant in a minute.



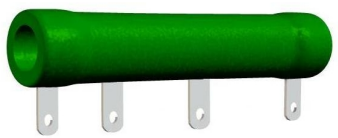
## Surface-Mount and Inline Resistors




In their continuing effort to shrink equipment, many manufacturers now use resistors that don't have leads that poke through the printed circuit board. Instead, they have little metal contact areas on each end which are soldered directly to the conductor traces on the surface of a PC board. The abbreviation for "surface mount" is **SMT**. Sizes go all the way down to grain-of-sand dimensions.

Another way to make resistors smaller is to put a dozen into a single package with leads coming out one side. This is called the "single inline package" or **SIP**.

## Tapped Resistors



A resistor may have one or more connections partway along its length. This kind of connection is called a **tap** and its physical position is usually (though not always) proportional to the percentage of total resistance at that point. For example, if a 100Ω resistor has a tap in the center, there is probably 50Ω between it an either end. The most common example is probably the high-power resistor used obtain a voltage that is some fraction of the supply voltage. That's called a **voltage divider** and we'll study it in chapter 6.

## Variable Resistors

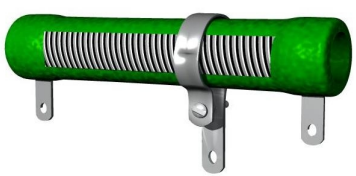
It's often necessary to be able to adjust the value of a resistor. This is done by providing a tap whose position can be changed. The schematic symbol uses an arrow to represent the adjustable tap.

A two-terminal variable resistor is called a **rheostat**. A three-terminal resistor, with an adjustable tap that can be set to any position along the resistive element, is called a **potentiometer** or "**pot,**" especially if its setting is intended to be frequently changed. A pot can be connected as a rheostat by simply not connecting one of the end terminals, or connecting the end terminal and the tap together.

A panel-type pot, like a rotary switch, usually mounts in a $^{3}/_{8}$" hole and usually has a tab to prevent rotation. The tap is also called a **wiper**.

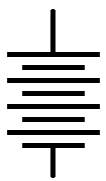
A tiny, low-power pot, intended to be adjusted once and then left alone, is called a **trimmer**. Its purpose is to adjust some operational parameter to a closer tolerance than could be obtained with standard-value parts.

At the other end of the scale, there are variable power resistors that are standard high-power resistors with a section of their nichrome wire coil exposed and a clamp-type tap that is adjusted, then screwed down.



The relationship between physical distance along the resistive element and fraction of total resistance is not necessarily linear. Special pots are made where most of the resistance is in the last 10% of wiper movement, or the first 10%. The shape of the position-versus-resistance curve is called the **taper**. In chapter 6, when we study series circuits, we will study variable resistors in more detail.

## BATTERIES



A battery is usually thought of as a device that stores energy. There is a device like that, but it's not a battery. It's called a capacitor, and we'll study it in EM2. A battery, on the other hand, *makes* electricity on demand from its store of chemicals. Its schematic symbol is a series of long and short lines; the end with the long line identifies the positive terminal. I've omitted any detailed study of batteries at this point because the whole of chapter 10 is devoted to batteries and battery power supplies.

We're going to take this as a somewhat arbitrary stopping point for this chapter. An electronics catalog has hundreds of pages of DC-related parts we haven't talked about yet, many of which will be covered later as your knowledge of electronic circuitry increases.

***End of Chapter 5***

# EM1 Chapter 6
# SERIES CIRCUITS

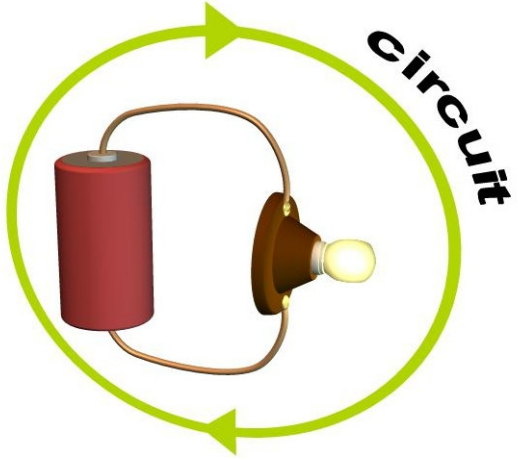
**by Xavier Uribe and Karl Eilers**

*Objectives covered in this chapter:*

- *Define "series circuit" and explain how it may be used in DC electronic equipment.*
- *Find the total resistance in a series circuit.*
- *Calculate an unknown current, voltage or resistance in a series circuit using Ohms law.*
- *Describe how to apply Kirchoff's voltage law to a series circuit.*

We've spent several chapters loading up on information, and we've now reached the point where we can put it to use. As mentioned previously, with current electricity – the kind we deal with most of the time – we're not talking about electricity that moves to or from anywhere, but *through*, in a complete circuit. We'll begin this chapter by expanding on that concept. We will be using the "conventional current" concept, where we think of current as positive charges flowing from the positive terminal of a voltage source to the negative terminal.

## ELECTRIC CIRCUITS

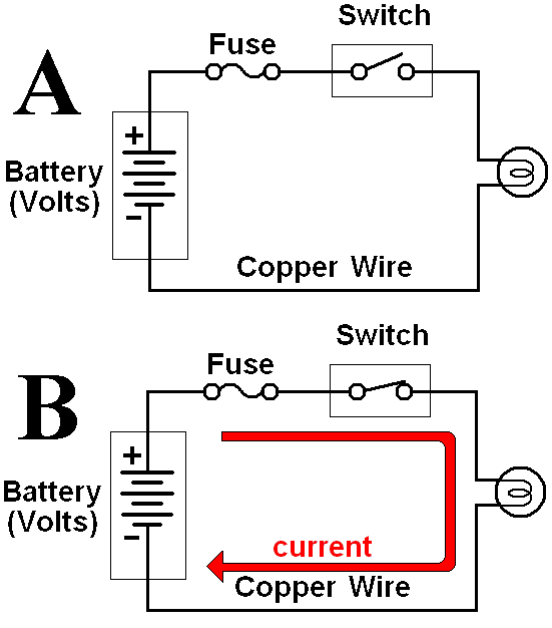


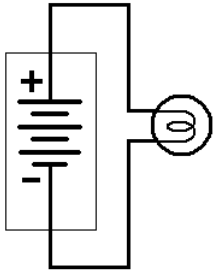

An electric circuit can be defined as a power source and a conductive path that allows current to flow outside the power source from the positive terminal to the negative terminal, then inside the power source back to the positive terminal, so as to form a continuous conductive loop. Usually, the circuit includes one or more other components, such as a fuse or circuit breaker, a switch, and a device that consumes the energy provided by the power source, all connected by copper wire.

A device that consumes the energy flowing through a circuit and converts that energy into work is called a **load**. In the circuit above, the load is an incandescent lamp where the current flowing through the circuit is converted into energy in the form of heat and light.

But this lamp could also be a hair dryer, a coffee maker, a toaster, an alarm clock, or any device that converts circuit voltage and current into work energy.

"A" at right shows an **open** circuit because the switch is open and, therefore, there is no path for the current to flow from one battery terminal to the other. Once the switch is closed, as at "B," we have a path between battery terminals via the load. This is a **closed** circuit.



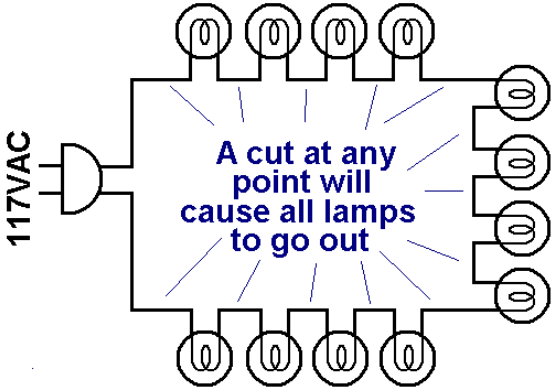




The simplest circuit has two components: an object such as a battery that supplies power, and an object that uses power, such as an incandescent lamp. There is only one way the lamp and battery can be connected: each terminal of the lamp is connected to one terminal of the battery.

## CIRCUIT TYPES

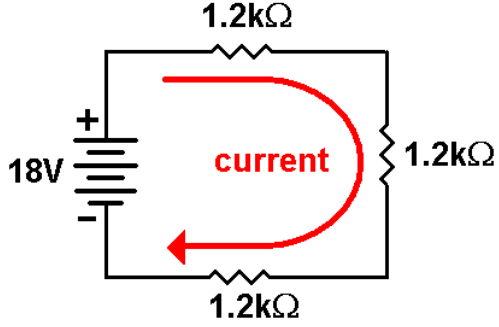
When there are more components, the possibility exists to connect them in several ways. There are three types of multi-component circuits: **series**, **parallel**, and **series-parallel** or combination circuits. In this chapter we will discuss series circuits.

In a series circuit, all components are connected serially; that is, the current flows through one after another in a single path. There is only one possible path for current to flow. If the electrical circuit is broken, resulting in an open circuit, none of the load devices will work because no current flows.



An example of a series circuit is a string of indoor holiday lights where one bulb burns out and the entire string goes dark.

The illustration below shows three resistances connected in one circuit loop. It's easy to see that electrical current only has one possible path to flow from the positive battery terminal to the negative battery terminal.




This points to a very important concept:

**In a series circuit, current measures the same at every point in the circuit.**

This is because the current being moved by the voltage source has only the one path to travel and, therefore, the current must be the same at every point. There are no branches where current can enter or leave the circuit, thus all the current that flows from the positive battery terminal must return to the negative battery terminal.

A second critical concept:

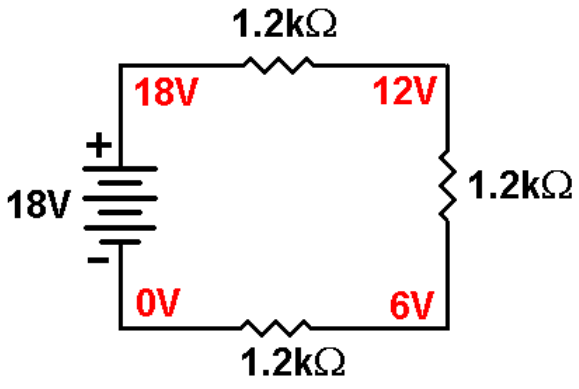
**The total voltage across all the series-connected loads is equal to the source voltage.**

Since the two ends of the series load string are connected directly to the source terminals, the sum of the voltages across the loads must be the same as the source voltage.

The third critical concept:

**The total voltage supplied by the source device is divided among the resistances in the circuit.**

For example, the illustration on the next page shows an 18 volt battery as the source and three 1.2kΩ resistors connected in series. Ohm's law tells us that the voltage across a resistance is proportional to the resistance and current values. Since all three resistances are the same (1.2k ohms), and the current through all three resistors is the same, the total voltage will divide into three equal voltages of six volts across each resistor.




If we call the negative terminal of the battery “zero volts,” then the positive terminal is +18 volts. The left-hand end of the upper resistor, being connected to the battery, is at 18 volts, while the right-hand end is at 12 volts. The right-hand resistor reduces the voltage from 12 volts to 6 volts, and the bottom resistor reduces the voltage from 6 to zero. As you learned earlier, the voltage reduction across a resistance is called a **voltage drop**.

There is no theoretical limit to the number of series resistances. A string of 20 indoor holiday lamps consists of twenty 6-volt lamps in series. When it's plugged into a 120-volt outlet, the first lamp drops the voltage from 120 to 114 volts, the second lamp from 114 to 108 volts, and so on down to the last lamp which drops the voltage from 6 volts to zero.

If the resistances are not equal, the voltage drops will not be equal. This situation is dealt with using Kirchoff's laws, which we will discuss shortly. First let's summarize what we've learned so far.

## REVIEW

In a series circuit:

1. Current *does not* divide; it is the same everywhere in the circuit.
2. Voltage *does* divide; a fraction of the total voltage appears across each resistance in the circuit.
3. The sum of all voltage drops equals the supply voltage.

## CALCULATING TOTAL RESISTANCE

Calculating the total resistance of a series string is easy; just add up the individual resistances.

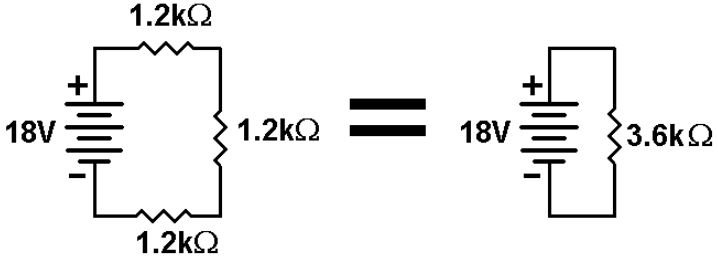
When resistors are connected together in series, the total resistance ($R_T$, also called equivalent resistance or $R_{EQ}$), is equal to the sum of the individual resistances. This is expressed mathematically as:

$$R_T = R_1 + R_2 + R_3 + \ldots R_n$$

where "n" is the total number of series resistances.

For example, in the graphic below, the total resistance connected to the battery is:

$$1.2K\Omega + 1.2K\Omega + 1.2K\Omega = 3.6K\Omega$$




Therefore, as far as the voltage source (battery) is concerned, it is connected to a single 3.6KΩ load resistor. We call the total resistance an **equivalent resistance** since the three 1.2KΩ resistors in the circuit are equivalent to a single 3.6KΩ resistor.

This is true for all resistances in a series circuit; the total resistance is equal to the sum of the individual resistances. Note that the combined resistance in a series circuit is *always* greater than any of the individual resistances in the circuit.

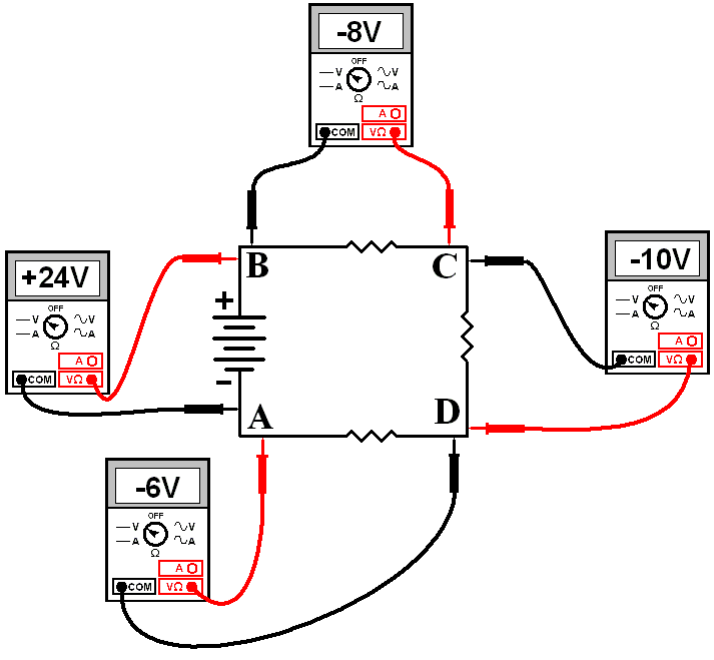
## KIRCHOFF'S LAW FOR VOLTAGES IN SERIES

Kirchoff's Voltage Law is a simple statement:

**The algebraic sum of all the voltages in a series circuit add up to zero.**

"Algebraic sum" means we pay attention to polarities. As you know, a voltage is the difference in charge across two points. This difference can be positive or negative.

Consider the circuit shown on the next page. Four voltmeters display the voltage across each of the four components of the circuit. The voltmeter connections are important: they are connected black lead to red lead, going in the direction of conventional current around the circuit. This meets Kirchoff's requirement that polarities be observed, and permits us to add voltages algebraically.




Suppose we start with a 24V battery. If a voltmeter is connected between points A and B, where the positive (+) red lead is connected to point B and the negative (-) lead is connected to point A, we will read +24 volts from B to A on the voltmeter. If we take the negative terminal of the battery as zero volts, we can say that the battery raises the voltage by 24 volts, giving us a positive 24 volts at the positive terminal.

Suppose we then take the voltmeter and measure the voltage drops across each resistor, following around the circuit in the same way, with the black lead as the starting point and the red lead as the ending point of each measurement. Suppose we read -8 volts (that is, the voltage drops by 8 volts) between B and C, then -10 volts between C and D, and -6 volts between D and A.

Let's see what we've got:

$$V_{B\text{-}A} = +24V$$
$$V_{C\text{-}B} = -8V$$
$$V_{D\text{-}C} = -10V$$
$$V_{A\text{-}D} = -6V$$

Therefore:

$$+24 + (-8) + (-10) + (-6) = 0$$

Again, “algebraic sum” means you must always account for polarities in your measurements (i.e., positive and negative leads of the meter).

## Finding Individual Voltage Drops with Kirchhoff's Voltage Divider Law

If we only know the resistances, how do we find the individual voltage drops? One way is to first find the current using Ohm's Law. If we know the individual resistances, we can add them up to find the total resistance. We already know the total voltage, and once we know the total resistance, we can find the current. Then we use Ohm's Law again, multiplying the current by the individual resistances to find the individual voltage drops. This is a perfectly valid method.

But there's a way of finding the voltage drop across a resistance without needing to know the current through the resistance as required using Ohm's Law. Any time we can find an answer by making one calculation instead of several, we're ahead.

The basic idea is that **the total voltage divides up by the same *proportions* as the resistor values.** This will be obvious if you think of Ohm's Law: since the current in a series circuit is the same everywhere, every ohm of every resistor must drop the same amount of voltage. So, if one resistor has twice as many ohms as another, it must drop twice the voltage.

This can be stated mathematically:

$$V_N / R_N = V_{TOTAL} / R_{TOTAL}$$

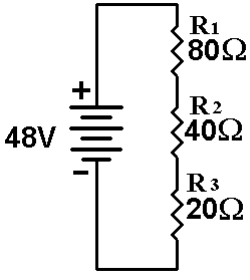
where Rn is any individual resistor. In plain English, the voltage drop across a resistor, as a fraction of the total voltage, is the same as its resistance as a fraction of the total resistance.

Now we get to use some of that algebra stuff. The rule about finding a particular quantity is to move the various terms around until the unknown term is isolated by itself on one side of the equal sign. We can do this by multiplying both sides of the equation above by $R_N$, giving us:

$$V_N = \frac{R_N \times V_{TOTAL}}{R_{TOTAL}}$$

That's Kirchoff's voltage divider law. If we have, for example, four series resistors and we want to find the voltage drop across $R_2$, the equation becomes:

$$V_2 = \frac{R_2 \times V_{TOTAL}}{R_1 + R_2 + R_3 + R_4}$$




Let's look at an example with actual numbers. In the circuit at left we have three resistances of known value connected in series to a 48 volt source. Using Kirchhoff's Voltage Divider Law we can calculate the voltage across any resistance as follows:

$$V_X = V_T \times \frac{R_X}{R_1 + R_2 + R_3 \ldots R_n}$$

where $V_X$= the voltage drop across resistor x, divided by the sum of all resistors in the circuit.

Using our previous circuit as an example, we can calculate the voltage drop across $R_2$ (40Ω resistor) using the steps shown to the right. Voltage drops across $R_1$ and $R_3$ can be calculated in a similar fashion, where the sum of the voltage drops across the individual resistors must equal the applied voltage, or, as Kirchhoff states, all voltages in the loop must equal zero volts when adding the negative drops to the positive source voltage.

$$V_{R2} = 48 \times \frac{40}{80 + 40 + 20}$$

$$= 48 \times \frac{40}{140}$$

$$= 48 \times \frac{40}{140}$$

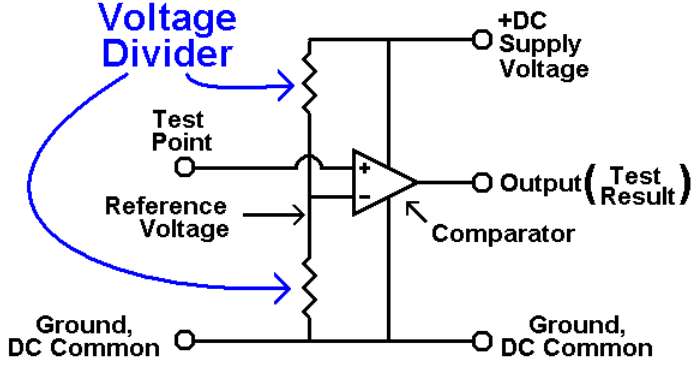
$$= 48 \times 0.286$$

$$V_{R2} = 13.7\text{V}$$

## VOLTAGE DIVIDERS

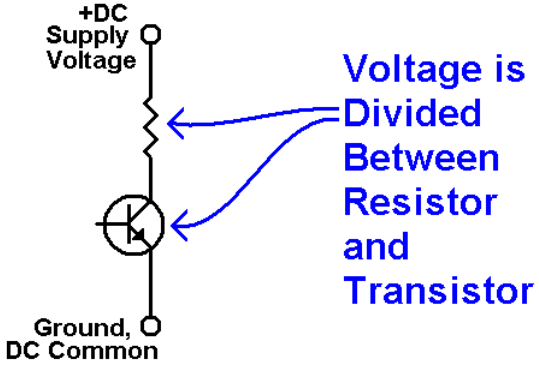
When a series string of resistors is used to obtain one or more voltages that are lower than the supply voltage, it is called a **voltage divider**. A complicated piece of equipment might contain dozens of examples.

For example, suppose we want to compare the voltage at a particular test point with a known reference voltage. If the power supply voltage is predictable and stable, we can use a voltage divider to tap off a certain percentage of it.

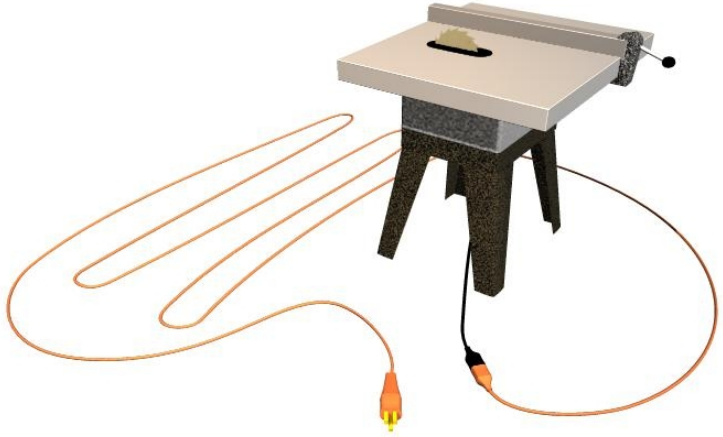


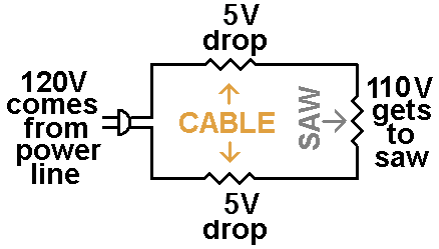
There actually is a device for making such comparisons. It's called a “comparator” and we'll study it in the chapter on integrated circuits.

Many circuits are not voltage dividers, strictly speaking, but do involve dividing a supply voltage between two or more circuit components. For example, the circuit below is part of a common 1-transistor amplifier arrangement. The transistor passes a certain amount of current, which has to go through the resistor to get to it. Thus the resistor and transistor form a series circuit. Any time current passes through a resistance, there will be a voltage across it. So the resistor and transistor split up the voltage, divider-style.



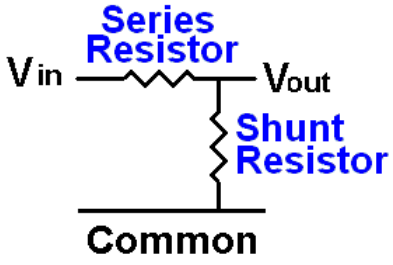

Many voltage dividers only exist because we can't get rid of them. A long extension cord and a big power tool, for example, form a voltage divider we'd rather not have.





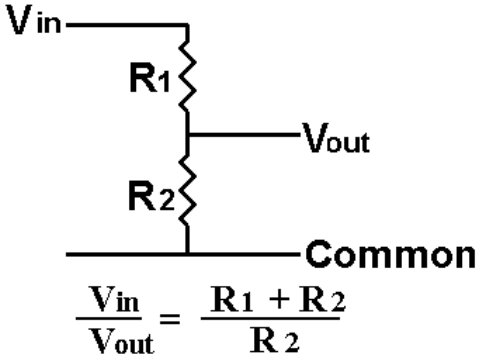
## Series and Shunt

The two resistors of a simple divider are often called the **series** and **shunt** resistors respectively – "series" because that resistor is in series with the output; the current must flow through it, and "shunt" because that resistor is across the output.




## Voltage Output

The output voltage of a voltage divider is a fraction of the input voltage. Specifically, the ratio of input to output voltage is the same as the ratio of total resistance to shunt resistance.




But we have to be careful! Whatever is attached between Vout and common counts as an extra shunt. That load and $R_2$ form a pair of parallel-connected resistors, or their equivalent. We'll study parallel resistances in the next chapter, but the effect on a voltage divider is to drag down the output voltage. So that extra load has to be taken into account.

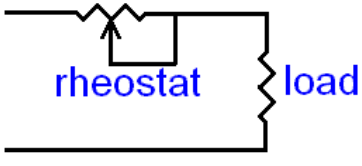
## Variable Voltage Dividers

As mentioned in chapter 6, some resistors are made so they can be adjusted. To review, an adjustable resistor, especially a low-power one, is called a **potentiometer** or **pot**. A small pot, intended to be adjusted once and then left alone, is called a **trimmer**. The movable connection is commonly called a **tap**, with high power resistors, or a **wiper** with low power ones.

If you look at the potentiometer symbol at left above, you will see that it's just a 2-resistor voltage divider where the ratio of upper to lower resistor can be adjusted.

## The Rheostat

As discussed in chapter 5, a variable resistor with only one end and the tap connected, or with the tap and the other end shorted together, is called a **rheostat**. It is equivalent to a simple 2-terminal resistor whose value can be adjusted.



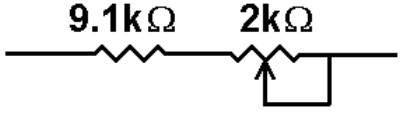

In the circuit where a rheostat is used, it is usually connected in series with a shunt load, thus forming part of a voltage divider. Or, the rheostat itself may be a variable shunt load.

## Using Series Resistors to Obtain a Precise Resistance

Sometimes a fixed resistor with a standard tolerance isn't close enough. Let's say you need a 10kΩ resistor with 0.1% tolerance, which means it has to be within 10 Ohms of perfect. You can buy resistors like that, but almost nobody keeps them in stock. So what do you do if you need a precision 10k resistor right away?

You start with a standard value resistor and **trim** it by putting a small rheostat in series with it. Here's how it works: we start with the next smaller standard 5% size, which is 9.1kΩ. This could be up to 5% off, or 405 ohms high or low – that is, it could be anywhere from 8,995 to 9,505 Ohms. So, to make sure we can reach 10k, the trimmer must be at least

$$10{,}000 - 8{,}995 = 1{,}005 \text{ Ohms}$$




Pots don't come in standard resistor increments. The next larger pot is 2k, which conveniently puts the likely setting in the middle of its range. The overall resistance is set with a precision ohmmeter – which is an issue all its own, but we're not going to deal with that until chapter 9. Using the trimmer pot, we can get a resistance that's much more precise than the 5% tolerance of the fixed and variable resistors.

***End of Chapter 6***

# EM1 Chapter 7
# PARALLEL CIRCUITS

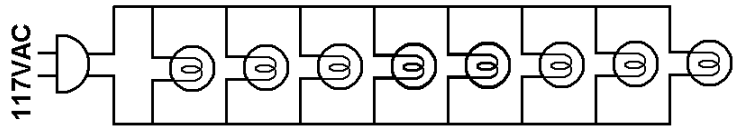
by Xavier Uribe and Karl Eilers

*Objectives of this chapter:*

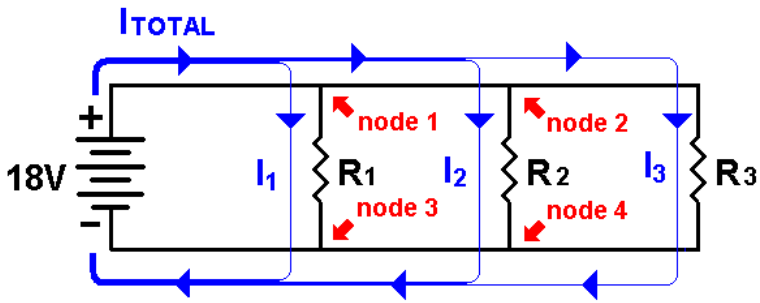
- *Define "parallel circuit" and explain how it may be used in DC electronic equipment.*
- *Solve for the total resistance in a parallel circuit.*
- *Describe how to apply Kirchoff's current law to a parallel circuit.*
- *Calculate current in a parallel circuit using the current-divider rule.*

In the previous chapter, we defined a series circuit as one where two or more components are connected so as to provide a *single* path for current, which flows serially through each component in turn. If the path is broken at any point, all current flow ceases. An example of a series circuit is a string of indoor holiday lamps, where if one burns out, all the lamps go out.

A parallel circuit is one where two or more components are connected so as to provide *multiple* paths for current. A fraction of the total current flows through each path. Because each component in a parallel circuit represents a separate current path, if one path is broken, current will still flow through the remaining components. An example of a parallel circuit is a string of outdoor holiday lamps, shown below, where if one lamp burns out, the others stay lit.




Neither type of circuit is inherently better than the other. Both are essential parts of the electronic systems we use every day.




A point where several wires join is called a **node**. It can be viewed as a summing point where various currents enter and leave. In the circuit above, we see three resistors connected in parallel across a battery. Current leaves the positive battery terminal. At node 1, some of the current branches off and flows through $R_1$, while the rest of the current goes on to the right.

At node 2, some of the current branches off and flows through $R_2$, while the remaining current goes off to the right and flows through $R_3$. Then the three currents recombine and flow back to the negative battery terminal. The total current leaving the battery at the top is equal to the current returning to the battery at the bottom.

The defining characteristic of a parallel circuit, then, is that all components are connected between the same set of electrically common points. In the parallel circuit above, we see that the upper ends of all three resistors are connected to the same wire that is connected to the battery's positive terminal and the lower ends are connected to the negative terminal. Each of these separate paths individually is called a **branch**.

Note that each resistance is directly connected across the 18 volt battery source.

From these facts we can derive the following rules for parallel circuits:

1. Voltage *does not* divide; it is the same value across all resistances in the circuit.
2. Current *does* divide; each resistance will have an individual current flow through it, which depends on the value of that resistance and the value of the total voltage applied by the source. The total current is the sum of the individual currents.
3. Total current flow is always greater than the current through any one branch.

## "PATH OF LEAST RESISTANCE"

Time to shoot down a widely believed piece of misinformation. You have always heard that "electricity takes the path of least resistance." That is flat-out wrong.

Suppose you have a space heater and a night light plugged into the same outlet. The space heater has about 9Ω of resistance, while the night light has about 3,000Ω. Obviously, the space heater is the path of least resistance by far, yet the night light still works.

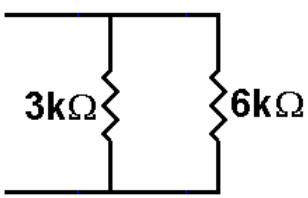
The truth is that electricity takes *all* available paths. Current flow in each path is inversely proportional to resistance in that path, just as it would be if that were the only path.

This "least resistance" thing comes from lightning, where electricity sort of probes around to find the easiest path through the air. Yet even in this case, you have surely observed that lighting often branches out into many paths. So let's take this "least resistance" thing and drop it in the trash can. In a parallel circuit, electricity divides up according to the rules presented on the previous page.

## PARALLEL RESISTANCE

In a series circuit, it is easy to find the total resistance: you just add up the individual resistances. In a parallel circuit, it's a bit more involved.

When resistances are connected in parallel, their combined total resistance ($R_T$), which is also an equivalent resistance ($R_{EQ}$), is always *lower* than any of the individual resistances. This will make sense if you remember that current flow is inversely proportional to resistance. Each additional resistor connected in parallel is an additional opportunity for current to flow. If the total current is greater than the current through any individual resistor, then the total resistance must be less than that of any individual resistance.




For example, in the circuit at left, the lowest resistor value is 3K ohms. Therefore the combined total resistance a battery would come in contact with is less than 3K ohms (3KΩ).

## THE PRODUCT OVER SUM FORMULA

The formula for finding the total or equivalent resistance for two resistances in parallel is:

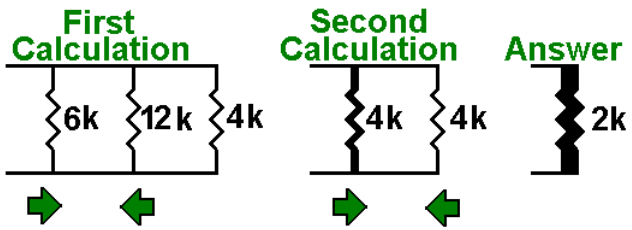
$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

For example, in the circuit on the previous page where a 3KΩ resistance is connected in parallel with a 6KΩ resistance:

$$R_T = \frac{3k \times 6k}{3k + 6k} = \frac{18k}{9k} = 2k$$

This formula is called the **Product over Sum** formula, and it is useful for any two resistances connected in parallel.

The formula can be applied to more than two resistances in a parallel circuit as long as only two are calculated at a time. Suppose we have a circuit of three resistances connected in parallel. To use the “Product over Sum” formula we take any two of the three resistances, calculate the equivalent of these two resistances, and then apply the same formula again using the result of the first calculation and the remaining resistance.
For example, for the circuit below, we use the Product Over Sum formula to calculate the equivalent resistance of 6k and 12k, then use it again to calculate the total resistance.




The same result would be obtained if the 12KΩ and the 4KΩ resistances were taken together first, then the result was taken together with the 6kΩ resistor.

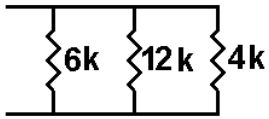
## THE RECIPROCAL FORMULA

When we have many resistors in parallel, this repeated calculation becomes cumbersome. In such cases it is easier to use the **reciprocal formula**. This formula is represented mathematically as:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots + \frac{1}{R_n}$$

In plain English, you add the reciprocals of the individual resistances to get the reciprocal of the total resistance. Once you've got that, you don't have to do any more calculation; $R_T$ is simply the total resistance.

For example, let's go back to our three resistance circuits of 6KΩ, 12KΩ, and 4KΩ in parallel. Using the "Reciprocal formula" the total circuit resistance is calculated as follows:




$$\begin{aligned} 1/R_T &= 1/6 + 1/12 + 1/4 \\ &= 2/12 + 1/12 + 3/12 \\ &= (2+1+3)/12 \\ &= 6/12 \\ &= 1/2 = 0.5 \\ R_T &= 1/0.5 = 2 \end{aligned}$$

**Answer: 2kΩ**

(Remember the rule about adding fractions – first convert so all the denominators are the same.)

As demonstrated, the same result is achieved as with the "Product over Sum" formula, but we were able to calculate using all resistances in parallel at one time. The choice as to which formula to use depends on what you are most comfortable with. Also note that the total resistance of 2kΩ is less than the value of the smallest resistance in our circuit. This will always be true for a parallel circuit.

Sometimes we get to use a shortcut. If two parallel resistors are the same value, their equivalent resistance is half the value of one of the resistors. For example, the equivalent resistance of two 12Ω resistors in parallel = 6Ω. If we have a 6Ω and a 12Ω resistor in parallel, that's the same as three 12Ω resistors in parallel, yielding a 4Ω result. Keep your eyes open for these opportunities.

## Using a Calculator With The Reciprocal Method

When using a calculator, it's easier to work with decimal reciprocals than fractions. As we saw in chapter 3, the decimal equivalent of a fraction is found by dividing the numerator by the denominator. The reciprocal of a number is found by dividing 1 by that number. For example, the fractional reciprocal of 5 is 1/5. If you divide 1 by 5, you will get 0.2, which is 1/5 in decimal form. If your calculator has a 1/X function, this becomes really easy:

**Enter the number**
**Hit 1/X**

Decimal reciprocals can be added without the bother of harmonizing denominators. As you find the reciprocal of each resistance, hit M+ to add it to the value in memory. Then do a MR recall to bring up the total, and do a 1/X on it to get the parallel resistance. In our example:

| | |
|---|---|
| **Enter** | **6** |
| **Hit 1/X** | **0.16666...** |
| **Hit M+** | **0.16666... is added to memory** |
| **Enter** | **12** |
| **Hit 1/X** | **0.08333...** |
| **Hit M+** | **0.08333... is added to memory** |
| **Enter** | **4** |
| **Hit 1/x** | **0.25** |
| **Hit M+** | **0.25 is added to memory** |
| **Hit MR** | **0.5 is recalled from memory** |
| **Hit 1/x** | **2 is the answer** |

Remember to clear the memory so you don't screw up the next calculation.

You may have noticed that we're doing the same thing we did to simplify series circuits: finding the equivalent resistance. As far as the power source is concerned, being connected to several resistances in parallel is the same as being connected to a single equivalent resistance.

## Calculating currents in a parallel circuit

In a parallel circuit, finding total current is easy: add up the individual currents. But first you have to find the individual currents.

That's easy too: use Ohm's law to calculate the current values from the supply voltages and the individual resistances.

But here again, Prof. Kirchhoff has given us a shortcut.

## Kirchhoff's Current Law for Parallel Circuits

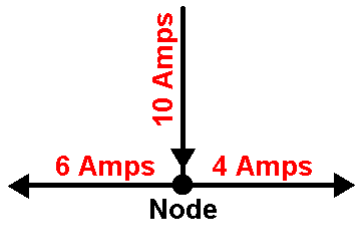
One of the most useful and powerful concepts for analyzing parallel circuits is that **the current entering a node always equals the current leaving it.** That's obvious when there are only two wires attached to a node; current has to be coming in via one wire and going out via the other.

However, the principle also holds true when there are many wires attached to a node, with current coming in via some wires and leaving via others.

Here is the principle of Kirchhoff's Current Law, stated formally:

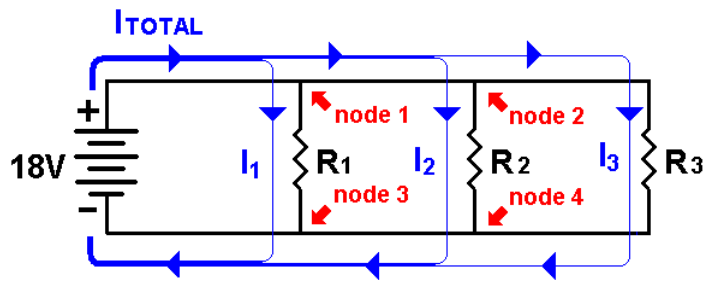
***The algebraic sum of the currents flowing through a junction (or node) is zero. Currents approaching the junction are positive (+) while currents going away from the junction are negative (-).***

A simpler way of saying this, perhaps, is Mr. Kirchoff's statement that **"The algebraic sum of all currents entering and leaving a node must equal zero."**

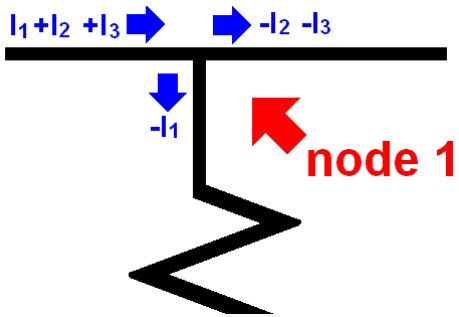



This is one of those things that, once pointed out, is so obvious it seems stupid. Naturally, currents flowing into and out of a point have to be equal. But when you're analyzing a piece of equipment – trying to figure out why, for example, the power supply voltage at a particular point in the circuit is lower than it's supposed to be – it's a handy thing to remember.

Let's take another look at our parallel circuit from the start of this chapter, adding the branch currents to each parallel segment.

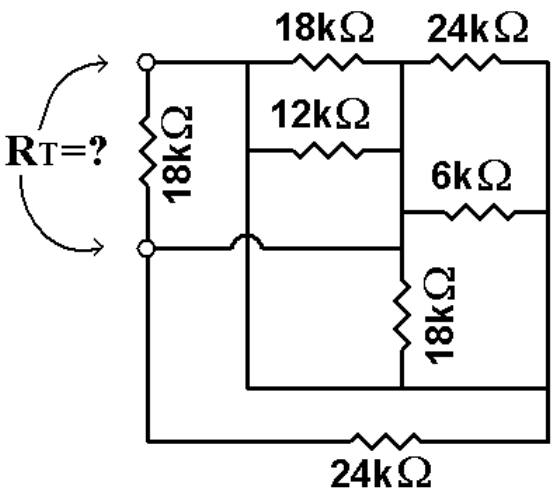


If we zoom in on node 1, we'll see a positive $I_1$, $I_2$ and $I_3$ entering the node from the left, a negative $I_1$ leaving downward, and a negative $I_2$ and $I_3$ leaving to the right.




We would see a similar equality of positive and negative currents at node 2, where the current splits again, and at nodes 3 and 4, where currents combine.

Let's try a more challenging example. See what you make of the circuit below.



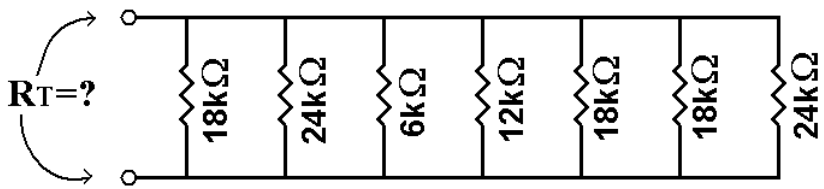

Give up? Okay, this is a good time to talk about a common quirk found in a lot of schematic diagrams.

Diagrams are often laid out by artists who do not understand the circuits they're drawing. Their concern is that all the connections are correct and the diagram looks nice on the page. Whether the parts placement makes any sense from a circuit operation standpoint often does not concern them; they don't know how it works anyway.

If you carefully trace out the circuit of every resistor end that's connected to the upper terminal, and then every resistor end that's connected to the lower terminal, you will find that each resistor is simply connected across the two terminals. In other words, this is simply seven resistors in parallel.

When you're confronted by a schematic diagram that some artist has laid out in such a way as to destroy all logic, one of the best ways to get a handle on it is to redraw it your own way. Hint: draw more positive voltages higher on the page. You won't be able to be consistent with this, because of cross connections and so on, but you can do it with each subsection of the circuit. Then currents will flow downward from plus to minus (or upward, if you like working in electron flow) and circuit operation will become clear to you.

The confusing diagram can be simplified so:




Now, notice: There are two 24k resistors; that's a 12k resistor. There's a 12k resistor; that and the two 24k resistors make a 6k resistor. There are three 18k resistors; they make a second 6k resistor. Finally, there's a third 6k resistor. This circuit is equivalent to three 6k resistors in parallel.

In other words, it's a big, complicated 2kΩ resistor. And we didn't even have to resort to the reciprocal or product-over-sum formulas.

Raise your right hand. Repeat after me: "I will never again give up on understanding something just because it looks too complicated at first glance."

## KIRCHOFF'S CURRENT DIVIDER RULE

In the last chapter, we saw that series resistors divide up the total voltage in proportion to their resistances.

In a parallel circuit, it is total current that is divided, and the division goes in *inverse* proportion to the individual resistances:

$$\frac{I_N}{I_T} = \frac{R_T}{R_N}$$

where $I_T$ and $R_T$ are the total current and resistance and $I_N$ and $R_N$ are the resistance and current of any single resistor.

That will make sense if you think about it for a moment: the lower a branch's resistance to current flow, the greater portion of total current it will hog. Duh.

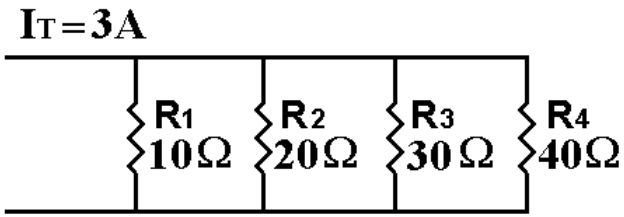
With the current divider rule, we don't need to know the voltage; only the current and the resistances. Suppose we have four parallel resistors, R1, R2, R3 and R4, and we want to find the current through R2. One way to do this is to first find $R_T$:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Then, rearrange the formula:

$$I_N = I_T R_T / R_N$$

and substitute values:For example:




Solving for $R_T$ with a calculator:

$$\begin{aligned} 1/R_T &= 1/10 + 1/20 + 1/30 + 1/40 \\ &= 0.1 + 0.05 + 0.0333 + 0.025 \\ &= 0.2083 \\ R_T &= 4.8\Omega \end{aligned}$$

Substituting values:

$$\begin{aligned} I_2 &= 3 \text{ x } 4.8 / 20 \\ &= 14.4 / 20 \\ &= 0.72A \end{aligned}$$

Let's do a quick common-sense check. 20Ω is about four times the parallel total of 4.8Ω, so $R_2$ should pass about a fourth of the total current. (Remember, current in a parallel circuit is inversely proportional to resistance.)

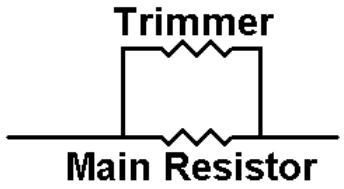
$$3A / 4 = 0.75A$$ Check.

## USING A PARALLEL RESISTOR AS A TRIMMER

In the last chapter, we saw how a series pot can be used to precisely trim a resistance. It is possible for a pot to become “noisy” as the contact between the wiper and the resistance element becomes contaminated. A more reliable method of trimming a resistance is to use a fixed trimming resistor.

It's not good practice to use a parallel-connected pot as a trimmer, because the pot can be adjusted to zero. But that objection does not apply to a fixed trimmer resistor. It may be better to trim with a parallel fixed resistor, because the circuit can be in operation, and the proper trimmer can be found by clipping a pot or resistor substitution box across the main resistor. Once the proper resistance is found, a fixed resistor can be soldered into the circuit.

With a parallel-connected trimmer, we start with a resistor that is a little higher than what we want to wind up with. Then we parallel it with a much higher trimmer resistor. For example, suppose we want a precise 1k resistor. Let's start with a 1.1k resistor, and let's assume it's a perfect, precise 1.1k.




$$1k = \frac{1.1k \times R_{TRIM}}{1.1k + R_{TRIM}}$$

$$1.1k + R_{trim} = \frac{1.1k \times R_{TRIM}}{1k}$$

$$1.1k + R_{trim} = 1.1x\ R_{TRIM}$$

*End of Chapter 7*

$$1.1K = 1.1\ R_{TRIM} - R_{TRIM}$$

$$= 0.1\ R_{TRIM}$$

$$11K = R_{TRIM}$$

# EM1 Chapter 8
# SERIES-PARALLEL CIRCUITS

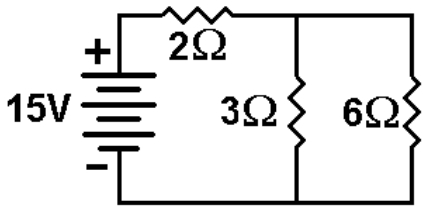
**by Richard Booth**

Objectives of this chapter:

- *Describe basic series/parallel circuit*
- *Calculate current, voltage and resistance in circuits*
- *Solve for an unknown values by substituting equivalent resistances*
- *Solve for unknown voltages, currents, resistances and power dissipation in a loaded voltage divider circuit.*

In the preceding discussions concerning series and parallel circuits, each type of circuit was viewed separately. When we combine both series and parallel circuits, a new circuit is developed and must be looked at as one complete circuit. This type of circuit is known as a **combination** circuit, or more commonly a **series-parallel** circuit. To solve problems for this type of circuit, apply the principles you learned earlier for series and parallel circuits. We will also look at a basic technique for solving DC combination circuits, which is to use equivalent circuits.

A series-parallel circuit has elements of both series circuits and parallel circuits, as in the circuit above right.



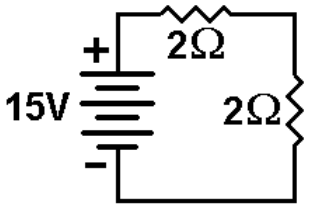

The first course of action to take when solving a complex series-parallel circuit is to identify the series and parallel relationships. In this case we have a 2Ω resistor in series with a pair of resistors, 3Ω and 6Ω, which are connected in parallel. Once these relationships are known, we use the rules learned for series and parallel circuits to replace series and parallel combinations with equivalent single resistances. This is done as many times as necessary to boil the circuit down to a single equivalent resistor.

Which parts of the circuit to simplify first is determined by inspection. In this case, the obvious thing is to solve for the parallel resistance of the 3Ω and 6Ω resistors using the product-over-sum method.

$$(3x6) / (3+6) = 18 / 9 = 2\Omega$$

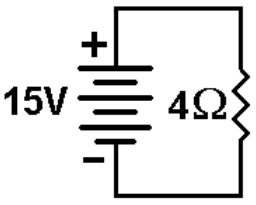
Now we can take the 3Ω and 6Ω resistors out of the circuit and substitute an equivalent 2Ω resistor (next page).

The total resistance ($R_T$), also known as the equivalent resistance ($R_{eq}$), of the circuit can now be calculated.




$$2 + 2 = 4\Omega$$

The original circuit can be redrawn with one load device depicting the equivalent resistance for the entire circuit. Having calculated the equivalent resistance for the series-parallel circuit, let's continue by finding the current, power, and voltage drops.




Voltage is obvious: since the 4Ω equivalent resistor is directly across the battery, the voltage across it is 15V.

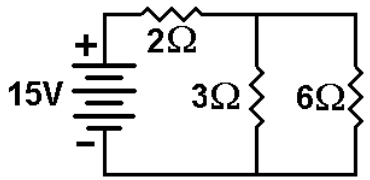
By Ohm's Law, current is

$$I = 15V / 4\Omega = 3.75A$$

To find total power:

$$P = 3.75A \times 15V = 56.25W$$

(You should get into the habit of mentally checking results to make sure you hit the right calculator buttons. 3.75 is almost 4. 4 x 15 = 60. 56.25 is almost 60. Check.)




Now let's go back to the original circuit and find voltage drop, current and power for each resistor. At this point, we have enough information that we could choose to do it any of several ways.

Let's start with the 2-ohm resistor. We know its resistance, we know the total current in the circuit, and we can see that all the current must pass through this resistor. So the voltage drop across it must be:

$$V = 2\Omega \times 3.75A = 7.5V$$

And the power it dissipates will be:

$$P = 7.5V \times 3.75A = 28.125W$$

(Mental check: since the 2Ω resistor carries all the current and drops half the voltage, it should dissipate half the total power. 28.125W is half of 56.25W. Check.)

So now we know everything about the 2Ω resistor – voltage across it, current through it, its resistance, and the power it dissipates.

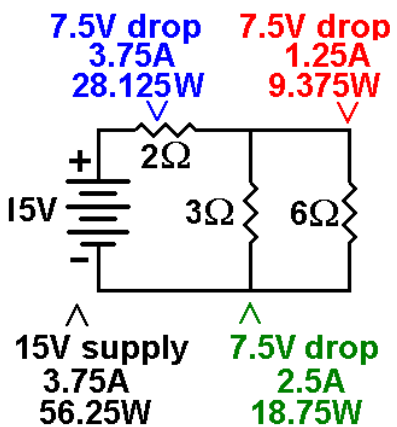
Next: if the 2Ω resistor drops 7.5V, that leaves 7.5V across the 3Ω and 6Ω resistors. Let's do the 3Ω resistor.

**7.5V / 3Ω = 2.5A**
**7.5V x 2.5A = 18.75W**

Now we know everything about the 3Ω resistor. Finally, we look at the 6Ω resistor.

**7.5V / 6Ω = 1.25A**
**7.5V x 1.25A = 9.375W**

(Mental check: since 6Ω is twice 3Ω, but the voltage across them is the same, current and power for the 6Ω resistor should be half the 3Ω resistor. 1.25A is half of 2.5A. Check. 9.375W is half of 18.75W. Check. The individual resistor powers should add up to the total power. 9.375 + 18.75 + 28.125 = 56.25. Check.) Now we know *every* quantity in *every* part of this circuit.

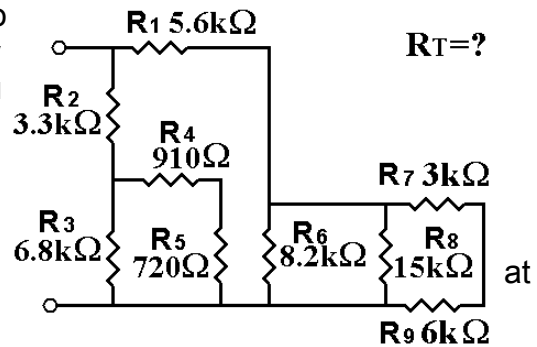



## Series-Parallel Circuit Exercises

### Exercise No. 1

We're going to start doing something you will see in actual equipment schematics: we're going to number the parts. In normal schematics, every resistor is $R_{SOMETHING}$, every capacitor is $C_{SOMETHING}$, every integrated circuit is $IC_{SOMETHING}$ and so on. This helps keep track of which part is which. It also helps coordinate the schematic with the parts list.

By now, I won't have to tell you how to simplify the circuit at right : you repeatedly replace series and parallel strings with equivalent resistors. See what you can do, then look the solution on the next page.




at

**Exercise 1 solution**

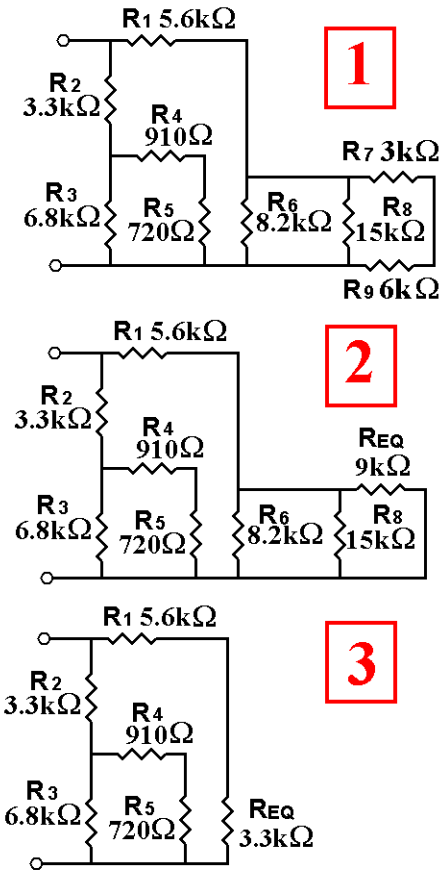
**1** The original circuit. In all calculations, we will be truncating to two digits.

**2** It often works best to start as far from the terminals as possible. First combine $R_7$ & $R_9$.

**3kΩ + 6kΩ = 9kΩ**

**3** Combine $R_6$, $R_8$ and $R_{EQ}$ using the reciprocal method.

**1/9 + 1/15 + 1/8.2**
**= 0.11 + 0.067 + 0.12**
**= 0.30**
**Reciprocal:**
**1 / 0.30 = 3.3**



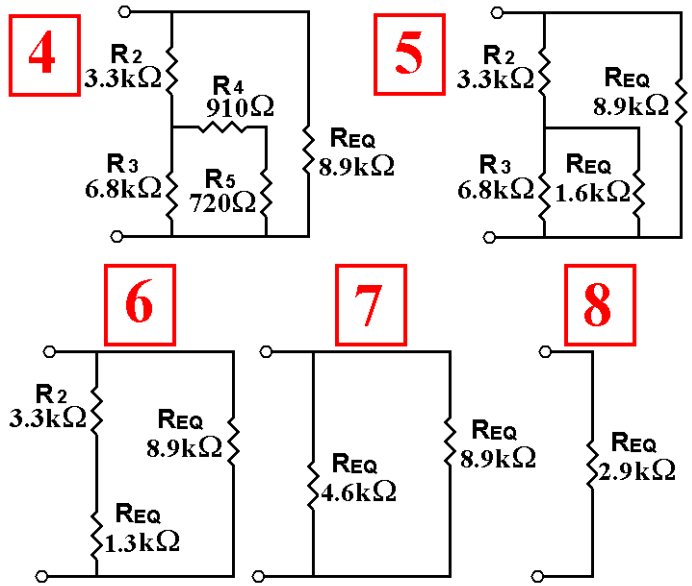

**4** Combine $R_1$ and $R_{EQ}$. **3.3kΩ + 5.6kΩ = 8.9kΩ**

**5** Combine $R_4$ and $R_5$. **910Ω + 720Ω = 1,630Ω**
Truncate: 1,630 becomes 1.6kΩ

**6** Combine R3 and REQ using product over sum method.

**7** Combine R2 and REQ.

**8** Combine to get final answer: **2.9kΩ**.



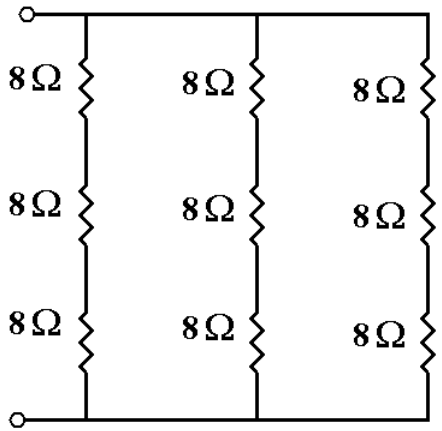

I bet you're wondering how much error we've picked up by truncating to two places. The error is about 143 ohms – around 5%. Assuming we're using 5% resistors, that's as close as we can get in any case, so it wouldn't have been worth making more accurate calculations.

Remember that, when faced with a combination circuit – or any complicated problem in life, really – it pays to take a moment to mentally gather the following information:

- What do I want to discover?
- What information do I have already?
- What tools do I have to apply to the problem?

If a few minutes are spent making focused observations, you can save hours of unnecessary calculations. Finding an answer is usually just a matter of asking the right question.

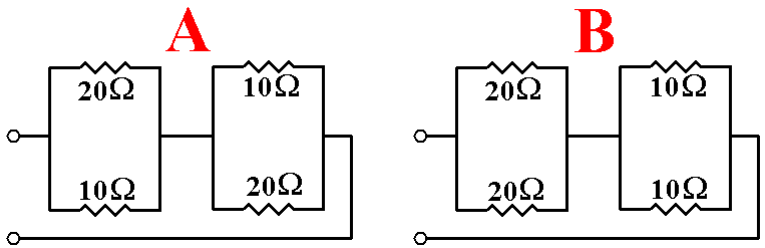
**Exercise No. 2:** What's the equivalent resistance of this circuit?




Answer: 8 ohms. 3 parallel strings of 3 series strings.

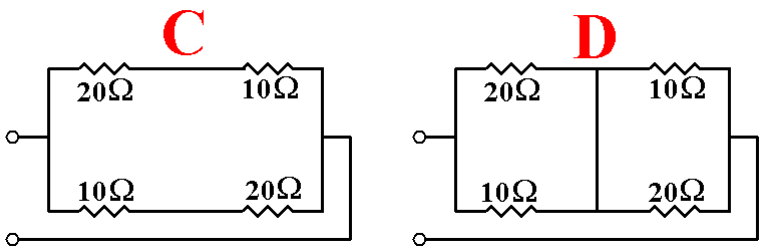
What this is, by the way, is a classic Bose 901 speaker.

**Exercise No. 3:** Are circuits A and B above right electrically equivalent? If not, what are the equivalent resistances?




Answer: no. In "A," 20Ω and 10Ω in parallel result in 6.7Ω. Two 6.7Ω resistors in series result in a total of 13.4Ω. In "B," two 20Ω resistors in parallel are 10Ω, two 10Ω resistors in parallel are 5Ω, and 10Ω and 5Ω resistors in series are 15Ω.

**Exercise No. 4:** Are circuits C and D below electrically equivalent? If not, what are the equivalent resistances?

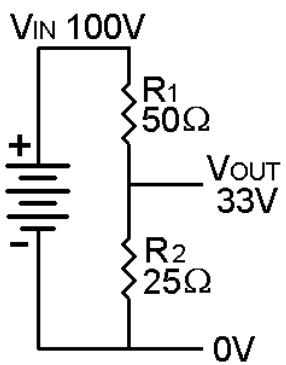


Answer: no. “C” is two 30Ω resistors in parallel. “D” is two 6.7Ω resistors in series. Total resistances are 15 and 13.4 ohms respectively. (Hint: try applying a voltage and note V at various points.)

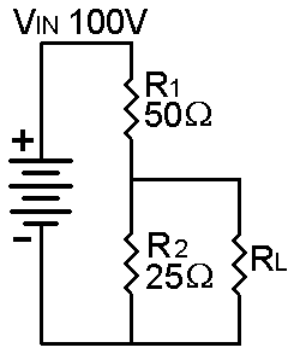
## VOLTAGE DIVIDERS REVISITED

When we studied voltage dividers in chapter 6, we only went as far as discussing the dividers themselves, without considering what they might be connected to. Now we are in a position to finish that discussion.

Let's assume we're working with a piece of equipment that has a 100VDC power supply, and we need 33V at 545mA to power one part of the circuit. So,we decide we need a voltage divider.




Recall that the ratio of input to output voltage is the same as the ratio of total resistance to the lower, shunt resistance, $R_2$ in the circuit at left. In this case, $V_{IN}$ is 100V and $V_{OUT}$ is 33V, a 3:1 ratio. If we make $R_1$ twice the value of $R_2$, then total resistance will be three times $R_2$. Just as a stab in the dark, let's make $R_1 = 50\Omega$ and $R_2 = 25\Omega$.




Now we connect the load and – rats. The output isn't 33V any more. What's wrong?

By now, you should recognize this as a series-parallel circuit, where $R_2$ and the load, $R_L$, are in parallel. It's not that hard to figure out the value of $R_L$. If it would have drawn 545mA with a 33V supply, that means it's:

$$R_L = 33V / 0.545A = 60.6\Omega$$

So we've got a 60.6Ω resistor in parallel with a 25Ω one. We don't even have to do the math to know that the parallel resistance will be lower than 25Ω, because a parallel resistance is always lower than the lowest individual resistor.

Try again. We could just choose $R_1$ to form a voltage divider with $R_L$, and omit $R_2$ entirely. However, most of the time, $R_2$ is retained, with a value calculated to draw 10% of the load current. This is called **bleeder** current. Though we've represented the load as a resistor, it may actually be some electronic gizmo that just looks like a resistor because it draws “X” current when “Y” voltage is applied. When power is turned off and the supply voltage begins to fall, it may stop drawing current entirely.

So, we put in a bleeder resistor to be sure the voltage does fall to zero. This is more or less standard practice. Let's find the resistor values.

Step 1: calculate bleeder current

$$\mathbf{10\% \times 545mA = 54.5mA}$$

Step 2: calculate bleeder resistance

$$\begin{aligned} R_2 &= 33V / 54.5mA \\ &= 3.3 \times 10^1 / 5.45 \times 10^{-2} \\ &= 0.6055 \times 10^3 \\ &= 0.6055k\Omega \\ &= 605.5\Omega \end{aligned}$$

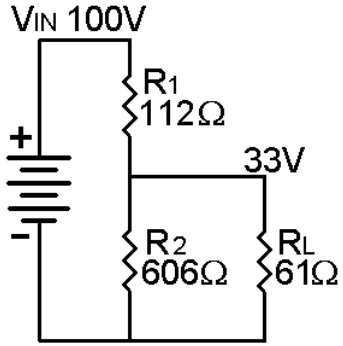
Step 3: calculate total current

$$\begin{aligned} I_T &= I_2 + I_{LOAD} \\ &= 545mA + 54.5\ mA \\ &= 599.9mA \end{aligned}$$

We'd be stupid not to truncate to 600mA; that's only a 0.2% error.

Step 4: calculate $R_1$

$$\begin{aligned} V_{IN}\text{-}V_{OUT} &= 100 - 33 \\ &= 67V \\ R_1 &= 67V / 0.6A \\ &= 112\Omega \end{aligned}$$




The final circuit is shown at left.

As mentioned in chapter 6, a voltage-divider supply wastes a high percentage of the power supplied to it. Our load, $R_L$, dissipates

$$\mathbf{P = 0.545A \times 33V = about\ 18\ watts}$$

However, the voltage divider dissipates

$$\mathbf{P_{R1} = 67V \times 0.6A = about\ 40\ watts}$$
$$\mathbf{P_{R2} = 33V \times 54.5mA = about\ 2\ watts}$$
$$\mathbf{P_{R1} + P_{R2} = 42\ watts}$$

Efficiency = power out / power in

**= 18 /42 + 18**
**= 18 / 60**
**= 0.3**
**= 30% efficiency**

Stated a different way, 70% of the power that goes into the circuit is wasted. Simply put, at these power levels a voltage divider probably wouldn't be used. However, at milliwatt levels, it's a simple, practical, cheap circuit that's used all the time.

One other limitation needs to be mentioned: the output voltage of a divider is only stable if the load current is stable. Many load circuits have varying current. The current drawn by a 2-way radio, for example, will be much higher on transmit than receive. A voltage divider simply cannot be used in this application. A more complicated circuit must be used, which we will study in EM3.

***End of Chapter 8***

# EM1 Chapter 9
# TEST EQUIPMENT AND METHODS

by John Baldwin, CETsr

*Objectives covered in this chapter:*

- *Explain analog meter construction, components and characteristics.*
- *Explain digital meter construction, components and characteristics.*
- *Describe the safe voltage and current operating ranges for multimeters, probes, and test leads.*
- *Describe how to perform voltage, current, resistance and power measurements.*
- *Discuss continuity and battery testers, resistance substitution boxes, and the Wheatstone bridge*

***Editor's note: There are dozens of different branches of electronics, and dozens of specialized kinds of test equipment to go with them. In this chapter we're going to present just a few of the ones most often used for DC measurements.***

***You can't always assume a measured value is accurate. First, the very presence of measurement equipment in the circuit can throw the measurement off. Second, the test equipment has limitations. You need to be able to tell whether a strange test result is caused by a malfunction in the equipment you're testing or error introduced by the test gear.***

***The important thing is not to have the very best test gear, but to be completely familiar with the gear you have. This is especially true in the case of the multimeter, which is the technician's indispensable all-purpose measuring instrument. You should know exactly how it measures and what its limitations are.***

***We're going to study meters first, then a very sensitive device known as the Wheatstone Bridge, and finally some miscellaneous special-purpose items.***

## METERS

Functionally, the four most common types of meters are:

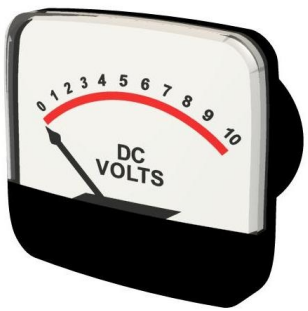
- The voltmeter, which measures voltage
- The ammeter, which is the more practical name techs have invented for “ampere meter,” which measures current
- The ohmmeter, which measures resistance.
- A multimeter, which is a combination meter that measures all three of the above, and often other parameters such as transistor gain.

Meters come in two flavors: analog, which display a quantity by means of a moving pointer, and digital, which display by means of a decimal number.

## ANALOG METERS

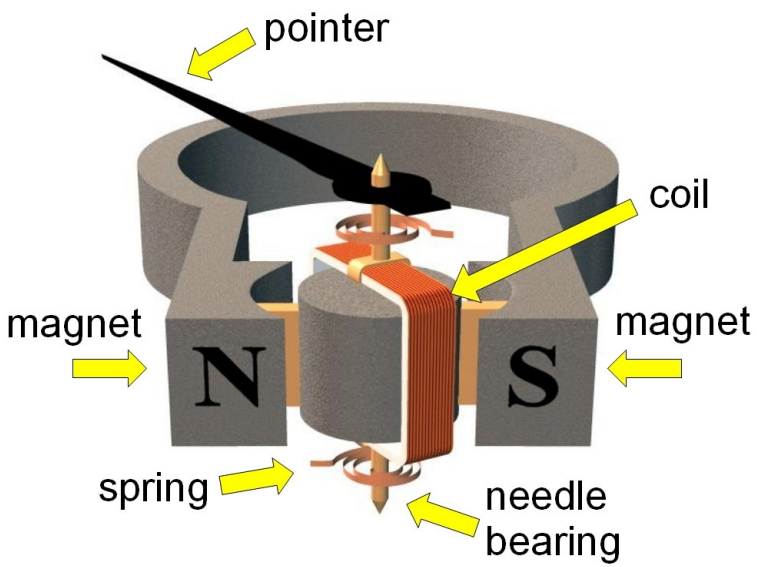
Despite what you'd think, analog meters are not obsolete. Analog meters have two advantages which recommend their use, even in the digital age.

First, their display is continuous (as opposed to the discrete steps of a digital meter), and their movement is easy for the eye to follow, making them better than digital meters for monitoring continuously-changing quantities.




Second, analog voltmeters and ammeters require no power supply. An analog ohmmeter requires a battery, but current is only drawn from it during actual measurement, so it can last a long time.

The most commonly used analog mechanism is called a **d'Arsonval movement**, named in honor of its inventor. Also referred to as a **basic movement**, this is the core mechanical system inside nearly all analog moving pointer type meters. It consists of a rotating coil of wire inside a permanent magnet structure. A pointing indicator is attached to the coil to show its position inside the magnetic field relative to the north and south magnetic poles. When no current is flowing through the coil, return springs on either side of the coil keep it in a rest position. (These springs also serve as connections to the coil.) When current begins to flow through the coil, it becomes an electromagnet which interacts with the permanent magnet to deflect the pointer. As current thru the coil increases, the angle of deflection increases.



A calibrated scale is positioned behind the pointer to indicate the value of current flow. With analog meters, it is important to avoid parallax error by closing one eye and keeping your open eye directly over the meter pointer. Some meters have a mirrored strip behind the pointer. Tilt the meter or move your head until the pointer and its reflection merge; then your eye is directly over the pointer and parallax error is eliminated.

Basic movements have a “full scale deflection” current rating that tells how much current it takes to deflect the pointer to the maximum allowable position. Typical current sensitivities for basic movements could be as high as 1mA but are more commonly on the order of 50 microamps.

A d'Arsonval movement is essentially a very sensitive ammeter. Extra components are added when we want to measure voltage or resistance.

## DIGITAL METERS

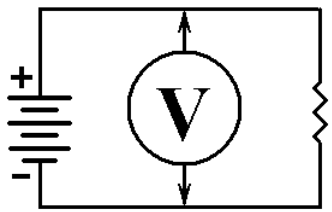
Digital meters use a multiple-digit readout display instead of an analog meter with a moving pointer. A digital meter is essentially a voltmeter; extra components are added to measure current or resistance. Like a camera taking snapshots, a voltage **sample** is taken several times each second, converted to a digital number, and displayed on a digital readout.

The main advantage of using a DMM is high accuracy. Where an expensive analog meter can be as accurate as 1%, the cheapest DMM will yield 2% accuracy and expensive ones can achieve .01 % or better in voltage and current measurements, and with special techniques, in resistance measurements.

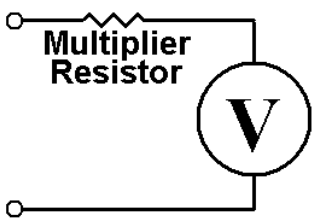
A digital meter requires a power supply. If the readout is an LCD display, which draws very little current, a battery can last a long time assuming you remember to turn the meter off when you're not using it. Cold temperature may affect the display LCD and it may not indicate until warmed up.

## MEASURING VOLTAGE

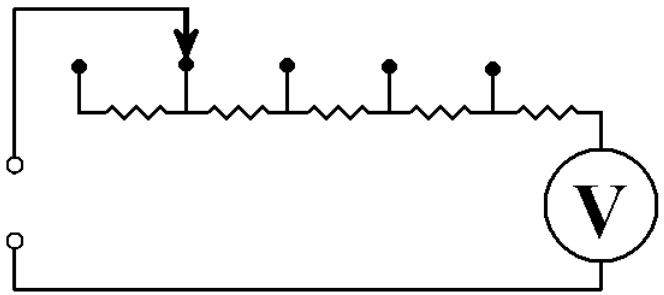
Voltage measurements are taken with the equipment under test powered up and operating. Since voltage is a potential across two points, a voltmeter is connected across the potential to measure it. The symbol for a Voltmeter is a circle with a V in it.




An analog voltmeter is constructed from a D'Arsonval movement by placing a resistor, called a **multiplier** resistor, in series with the basic movement. Using Ohm's Law, the resistor is calculated so that, when the intended full-scale voltage is applied, the current required to fully deflect the meter will flow. Voltmeters can be calibrated so that very high or very low voltage can be measured, simply by choosing the right multiplier resistor.




A switch may be provided to outfit the meter with many ranges, such as 1V, 10V, 100V, and 1000V selectable with a **range switch**. Multiplier resistors are used in each range to increase the maximum voltage that can be read by the meter. The value of the resistance can be calculated with Ohms Law, R = V / I, where V is the full scale voltage desired, and I is the maximum full scale current rating of the basic movement.



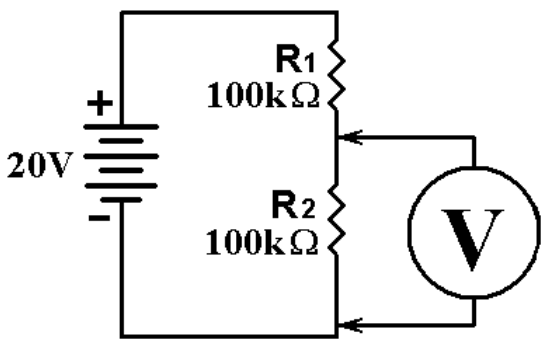

We've mentioned the problem of upsetting the quantity we are trying to measure. In a voltmeter, this condition is avoided by having a high resistance, so it draws very little current. An ideal meter would have infinite resistance; that is, it would be an open circuit. Fortunately, a multiplier has a high resistance, increasing the internal resistance of the basic meter so that the voltmeter, including the multiplier resistor, loads the circuit under test less than if a meter movement were to be used alone.

This brings up an interesting point: the resistance of a multiple-range analog voltmeter changes depending on the range chosen. A voltmeter's resistance is often rated in **ohms per volt**.

A very typical value is 20,000 ohms per volt, meaning that the meter's resistance is 20k ohms when set to the 1V scale, 200k when set to the 10V scale, 2meg when set to the 100V scale and so on.

## Voltmeter Loading and Ohms/Volt rating

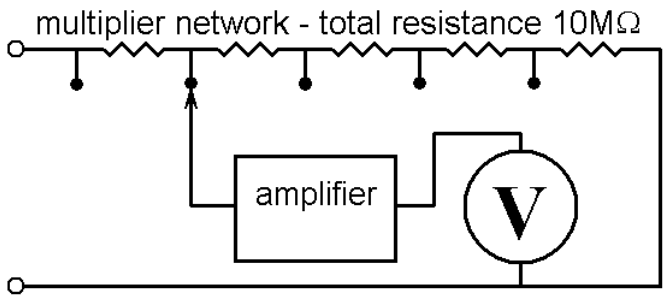
Let's talk a bit more about not letting measurement screw up what's being measured. When using an analog voltmeter, the multiplier resistance and basic meter movement will load the circuit under test because of the current drawn from the circuit to power the meter movement. The voltmeter is connected in parallel to the circuit under test, as in the circuit below. If the meter is connected to a circuit that has high resistance values, such as a voltage divider of two 100K resistors in series, and the meter has an internal resistance of, say, 200K, the meter resistance will load the circuit and give an erroneous reading.




The circuit would normally have 10 volts at the junction between $R_1$ and $R_2$, because the equal value series resistors will divide the applied voltage equally. But if a 20kΩ/volt meter is used in the 10 Volt range, the effective meter resistance will be 10 x 20 kΩ or 200 kΩ. When the meter leads touch test point A and ground, the series circuit will become a series-parallel circuit with the meter resistance of 200kΩ in parallel with R2's value of 100kΩ. That parallel branch will have a resistance of 66.7kΩ, and the total resistance will drop to 167kΩ, and cause the current to increase to 0.12 mA. The voltage drop will increase across $R_1$ to 12 Volts, and 8 Volts will be left across the meter and $R_2$. The error in this case will be: (10 – 8) / 10, which is a 20% error.

## Vacuum Tube and FET Voltmeters

To overcome this problem, the vacuum-tube voltmeter or **VTVM** was developed. This kind of meter places a resistance-multiplying tube between the input and the meter movement, so the circuit-loading resistance of the meter is at least 10 MΩ (megohms). This is a very light load and does not affect the measurement, except when measuring a circuit with extremely high resistances.




**VTVM OR FET VOLTMETER**

An amplifier requires a power supply, and in the tube days, that meant you usually had to plug a VTVM into a wall outlet. Nowadays, the tube has been replaced by a field-effect transistor, and FET meters can run on batteries. But, you still have to remember to turn them off when you're done using them, or you'll run the batteries down.

Digital voltmeters almost always have an input resistance of 10 MΩ or higher, so they are equivalent to a VTVM.

## WAVEFORMS AND MEASUREMENT ERROR

Something to keep in mind when measuring an AC voltage: AC voltmeters are calibrated to read correctly with a 60Hz sinewave. Other waveforms, other frequencies, all bets are off. More on this in EM2.

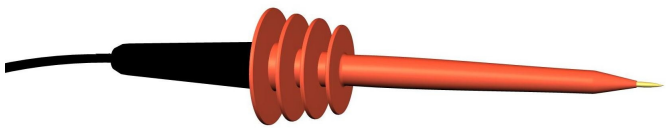
## SAFE VOLTAGES

Care should be taken not to connect an analog voltmeter to a voltage that will cause the pointer to hit the limit pin. A gentle nudge now and then won't hurt, but a large overvoltage may bend the pointer, ruining calibration. A digital meter can usually take an overvoltage up to at least the highest range of the meter. A “1” or “E” will appear on the readout to tell you when the meter's full-scale voltage has been exceeded.

Observe the personal safety precautions outlined in chapter 2 when working with high voltages. When a meter's range knob has both a 2.5V and a 500V setting, many experienced techs who should know better are lulled into treating them the same.

## Measuring Very High Voltages

There's no safe way to connect a voltmeter directly to a very high voltage. Instead, high voltage probes are used with voltmeters to extend the voltage range to many kilovolts. The multiplier resistor is built into the probe itself, and is typically several hundred megOhms of resistance.



HIGH VOLTAGE PROBE

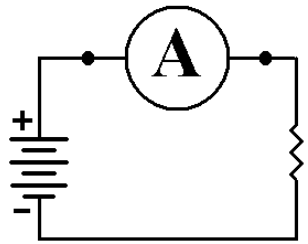
High voltage probes offer a convenient handle, usually about 12 inches long, for good isolation and protection against shocks. A ground lead is required so that the shock hazards are minimized and a discharge path for high voltage arcing is provided. A high voltage probe offers an additional safety benefit: if you should come in contact with the high voltage at the meter end, the very high-value multiplier resistor in the probe, between you and the actual voltage source, will limit the current. Anybody who works with CRT displays or high power transmitters pretty much has to own a high voltage probe. In some cases, a meter is built right into the probe, which reduces the number of pieces you have to deal with – always a good thing around high voltages, where you have to keep your wits about you.

## MEASURING CURRENT

Current measurements are made while the equipment under test is powered up and operating. The symbol for an ammeter is a circle with an “A” in it.

There are two ways to measure current, the direct method and the indirect method.

## Measuring Current Directly




In the direct method, an ammeter is placed in the circuit under test, so the load current flows through it. It is therefore important for the ammeter to have as low internal resistance as possible so that the total resistance of the circuit is not affected during measurement. An ideal ammeter would have zero resistance.

This also means that the circuit has to be broken open or interrupted to find two points to be able to connect the meter. Current measurements are sometimes difficult to perform because of this requirement.

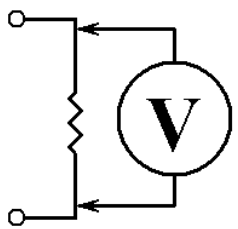
## Finding A Point To Insert An Ammeter

It may not be necessary to cut a wire to insert an ammeter into the circuit. It may be possible to remove a fuse and place the meter across the fuse holder contacts to measure current thru the circuit.

If the technician is careful, an ammeter can be connected across an open switch to measure current flow, but then the circuit will become active when the meter is connected. Remember, an ammeter has low resistance, so placing one across an open switch is equivalent to closing the switch. Bear in mind that if you're working on a malfunctioning piece of equipment, current may be higher than it's supposed to be. Removing a fuse deprives you of the fuse's protection. Excessive current can burn out an ammeter; start with the meter on its highest setting and switch down one step at a time.

## Measuring Current Indirectly

The indirect method of measuring current is to put a small resistance in the circuit, then measure the voltage drop across it with a voltmeter. In fact, a digital ammeter is actually a voltmeter calibrated to measure the drop across a low internal resistance.




If there is already a resistance in the circuit at the point where you want to measure the current, you can use the indirect method to measure current without breaking the circuit. First measure the resistance of the device without power applied as discussed below under resistance measurements, or use the known resistance from the specifications. Then apply power and measure the voltage across the resistance. Use Ohm's Law to convert voltage and resistance to current.

If, for example, the device is a 1kohm resistance, then the measured voltage will indicate the value of current in mA.

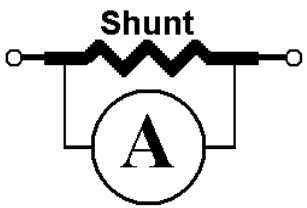
From Ohm's law, I = V/R. If 10 volts is measured, then

**10V/1kOhms = 10 mA**

The indirect method offers another advantage: where high current is to be measured, the meter can be placed at a distance from the equipment without running heavy wires to and from the meter. For example, in power plants, most of the ammeters are actually voltmeters, connected across resistances far removed from the meters.

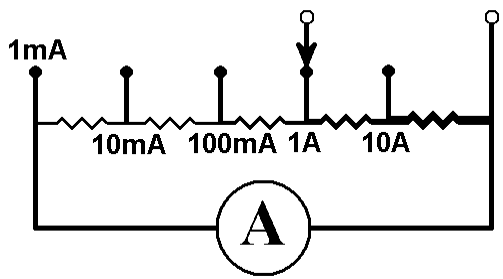
## Ammeter shunts

A 50-microamp d'Arsonval meter is quite sensitive. To measure higher current, a **shunt** is placed in parallel with a basic meter movement to increase the range of current measurement as shown below. A shunt is a very low-value resistor which, as its name implies, shunts most of the current past the d'Arsonval movement.




For example, if a basic movement has a full scale current rating of 1 mA and it is necessary to measure up to 100 mA of current, the shunt would need to carry 99 mA of current around the meter. The resistance of the shunt would be 99 times smaller than the resistance of the coil of wire in the basic movement. If the basic movement was 100 ohms, then the value of the shunt would be about 1.01 ohms. (Verifying this would make a good Ohm's Law exercise.)

Typically, shunts have very low resistance. A range switch may be provided to select among several shunts, shown below, permitting the meter to measure a wide range of currents.




The tech must keep in mind that the test leads used with multimeters have significant resistance, sometimes as much as several tenths of an ohm. In a low-voltage circuit, they may change the circuit operating parameters. The measured current will be accurate at the time of measurement, but it may be different from the current that flows normally, when the meter is not in the circuit. Only experience and a solid knowledge of Ohm's Law will tip you off when this might be a problem. When in doubt, cut a wire and attach the ends directly to the meter. Since this wire is always in the circuit, even when the meter isn't, the measurement will be accurate.

## SAFE CURRENTS

Assuming you observe the cautions in chapter 2 and don't wear jewelry, excessive current isn't much danger to you, except to the extent that you may get a burn from something hot. However, excessive current can quickly destroy the meter. Since current is actually flowing through it, the meter is quite vulnerable. Be sure it's set to a high enough range before you connect it.

When a piece of equipment is first turned on, there is usually a current surge that's an order of magnitude higher than normal operating current; in some cases you can see the lights dim for an instant. If there's an ammeter in the circuit, especially an analog one, it can be ruined.

This can be prevented from happening by shorting across the meter while power is first applied, then removing the short.

If a very high current is to be measured, an external shunt is used with the ammeter. The shunt directs the majority of the current around the meter, which is more practical than building a meter that can actually handle the high current. The shunt may become warm if it's connected too long. With this method, it is critical that connections be made properly: the circuit connections are made directly to the shunt, and the ammeter is then connected across it. This keeps resistance and less-than-perfect connections in the ammeter wiring from affecting the measurement, and likely destroying the ammeter. In this case, it's easy to avoid a turn-on overload: don't connect the ammeter across the shunt until the equipment is up and running.

## MEASURING RESISTANCE

Resistance is measured with equipment powered off. The measuring device, an ohmmeter, is also used to measure the resistance of individual components.

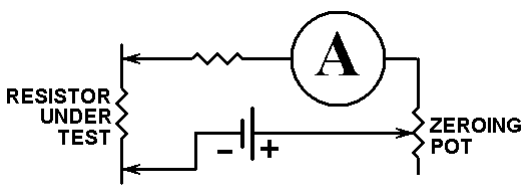
To make a measurement, the meter is connected across the component under test. When testing a component in-circuit, parallel paths must be removed to avoid an erroneous reading, perhaps by unsoldering one end of the component.

If a known resistance is to be checked, ohmmeter testing can be used to compare the actual value to the resistance specification of the component. A radically different value indicates that the component has been stressed by excessive voltage or heat.

If the measured resistance slowly changes at first, what is probably happening is that the voltage being supplied by the meter is charging up a capacitor in the circuit. Wait until the reading stabilizes, then note the measurement.

## The Ohmmeter

A typical Ohmmeter can measure resistance from fractions of an Ohm to many megOhms. Usually an Ohmmeter is included in a multimeter and not found by itself, except in laboratory grade instrumentation.




An Ohmmeter is made by adding a battery to an ammeter. The battery supplies a voltage to an unknown resistance; the resulting current is measured by the ammeter and the resistance value which results, calculated via Ohm's Law, is shown on the scale.

This means you can only measure resistance in any part of a circuit when the power is turned off. Otherwise, the circuit's own voltages will cause an inaccurate reading – and may destroy the meter. Also, it is important not to touch the test lead tips, as skin resistance will shunt the measured resistance and cause errors. This is especially important when measuring a high resistance such as 100k Ohms.

A zeroing potentiometer is often included, which is used to cancel the resistance of the test lead and other parts of the meter circuit. For shorts, or for checking fuses and switches, a low ohms range should be selected so that zero ohms can be read. Zero the meter first before checking the component by touching the leads together. Zero should be displayed on a digital meter or full deflection on an analog meter. A good fuse should read close to zero ohms. A switch should show zero in the closed position and infinity in the open position. If a zero reading can not be obtained on a meter, replace its battery.

Digital ohmmeters often do not include zeroing pots. In this case, short the test leads to measure their resistance, and then subtract that figure from every measurement you make. Test lead resistance will only be significant on the lowest ohmmeter ranges.

## SAFE RESISTANCE MEASUREMENTS

Resistance measurements pose no danger to the tech, because the equipment under test is powered down and the voltage and current are limited to what the meter can supply. However, improper measurement can damage the meter or the component it is measuring.

Current from ohmmeter circuits is higher in low resistance ranges, as much as several hundred mA. Damage could occur to components that are sensitive to higher currents, and it is recommended to use high resistance ranges on a meter to check delicate components such as signal diodes.

In medical and some other special kinds of equipment, there are fuses rated in milliamps. If you use a low resistance range to measure those fuses, you will find that they're always blown – because you blew them with the ohmmeter! Use a high resistance range to measure fragile components.

The greatest danger to the meter is voltage in the circuit being measured. After turning off the equipment, be sure power capacitors are discharged before connecting the ohmmeter.

## MEASURING POWER

Power can be measured with a watt meter, which is a comparatively rare item, typically used where continuous power monitoring is required and the meter is permanently installed.

Since power is voltage times current, a watt meter must measure both quantities. For this reason, watt meters have three or four terminals to allow making both measurements at once. Voltage and current measurements are combined inside the meter to give a power reading.

Power measurements are more commonly made indirectly, by measuring voltage and current separately, then multiplying to find power.

Heat is also an indication of power dissipated in a circuit and a simple way to measure power is with your finger. After you've worked with a particular kind of equipment for a while, you will know the normal temperatures of representative parts. If a normal amount of heat is felt on the component, then it is probably OK, but if it is felt to be too cold or too hot, then a problem could be causing the difference in touch. The problem is not necessarily with the component itself, but may be in another part of the circuit, causing too much or too little current to flow through the component your finger is on.

## SAFE POWER MEASUREMENTS

In addition to the usual cautions about voltage and current, where power is involved, heat is involved. Take care not to burn yourself; take care that things that get hot don't melt or burn anything. An electronic component can get hot enough to set paper or cloth on fire without any change in appearance.

## MULTIMETERS

A multimeter is also called a **Volt-Ohm Meter** or **VOM** for short. Combining meter functions of reading Volts, Amps and Ohms into one unit makes using a multimeter much more convenient. Multimeters are for field or bench work where more than one type of measurement needs to be taken often. This is what most techs do, most of the time. A single-function meter is used where a single quantity needs to be measured often or continually monitored. For example, in a power plant, there are many points where voltage must be monitored; thus there are many voltmeters. On the other hand, an ohmmeter wouldn't be used in a power plant very often.

## A REPRESENTATIVE ANALOG MULTIMETER

The versatile Simpson 260, shown to the left, has long been one of the most popular multimeters for techs when they're not using a digital meter. In the photo to the right, controls and connections can be seen.

Usually, the test probes are connected to the "Common" and the "+" input jacks at the lower left corner of this multimeter. The black test lead is connected to the Common input and the red test lead is connected to the "+ ". These connections never have to be changed for most voltage, current and resistance measurements; the necessary changes are made internally by the switches.

The other input jacks are for special measurements, such as low current (50uA, which provides direct access to the coil of the D'Arsonval movement), low voltage (+1 v full scale), high current (10 Amp full scale) or high voltage (1000 V). The center knob is for choosing what is being measured – voltage, current or resistance – and choosing the multiplier. A zero Ohms knob is on the right side for

zeroing meter for Ohms measurements. When measuring volts, the small knob on the left selects the kind of voltage. The first position, +DC, measures DC volts, with the red lead positive. The second position, -DC, reverses the leads so connecting the black lead to the positive will give the voltage reading. The third position, AC, is for measuring AC voltages.

Note that for voltage, there are five ranges available on the center knob; for current and resistance there are three. If you choose a voltage or current range that's too low, the needle will hit the limit peg on the right. If it hits hard enough or often enough, the needle will be bent and the meter's accuracy ruined. Before you take a voltage or current measurement, set the selector to the next value higher than what you expect. For example, to check the accuracy of a 30-volt supply, set the selector to 50 volts. If you don't know what to expect, set it to the highest voltage range. (But if you don't know what the voltages in the unit are, you shouldn't be working on it!)

When multiple functions are combined in one meter, scales are added to the face, as in the picture to the right. At first appearance, it looks more complicated to use than individual meters designed for specific functions. However, you only use one scale at a time. After you find the right scale, using a multifunction meter is the same as using a single-function one.

Some scales are linear and some are not. The voltage scales are linear; on the 10V scale, the distance between the marks denoting 0V and 2V is the same as the distance between 8V and 10V. The resistance scale, on the other hand, is nonlinear. At the right end of the scale, the distance between 1 and 2 ohms is about the same as the distance between 20 and 40 ohms at the left end.

## MULTIMETER PRECAUTIONS

Trying to measure an excessive current can burn out the shunt resistors in a cheap meter. In a good one like the Simpson 260, there's a fuse you can replace – but you will have to open the meter to do it, and it's a pain, so try to avoid that.

The easiest way to destroy the ohms function is to try to measure a resistance when there's power applied to it. A capacitor you've forgotten to discharge can store enough juice to whack the needle against the peg really hard. When this happens, there's a distinctive “tink” sound which tells you that your expensive meter just had its accuracy ruined.

## DIGITAL MULTIMETERS

The functions and ranges of a DMM are equivalent to those of an analog multimeter. Better DMMs have auto-range and auto-polarity; no need to change position on a range switch on an autoranging meter, nor watch DC polarity connection, as the display can indicate either a + or – for auto polarity convenience. A DMM may also have a memory function, so you can connect the test leads, push a button, and read the numbers later at your convenience. This is a worthwhile safety feature, as you can watch your hands and test leads as long as they're inside a piece of equipment, and then remove them before looking at the meter.

Like an analog meter, you can only depend on a DMM to be accurate when measuring DC, and AC sinewaves at 60Hz. Most analog meters are good to at least a few hundred kHz, but many DMM's are inaccurate at any frequency above 200Hz. More expensive meters have a true-RMS measuring function that may also work at higher frequencies. Evaluate specs carefully and assess your needs before you buy.

(I've just gotten ahead of myself, introducing a bunch of AC terms we won't cover until EM2, haven't I. Sorry, no good way to avoid that – every multimeter I know of includes AC measurements. If you want to know a little more about these quantities and don't want to wait until EM2, check them out on Wikipedia.)

Digital meters often have additional functions. For example, many have a special setting for testing diodes and transistor gain. A very useful feature is an audible beeper for continuity testing (see below).

## WHICH IS BETTER?

Whether an analog or a digital meter is better depends on the situation. The advantages of digital meters are easy to read scales, accuracy and low cost. An analog meter is often preferred to show minimum and maximum values where a changing reading is expected.

## TEST LEADS

Test leads come in many styles for the type of circuit testing to be performed. Common types are needle points for quick point to point circuit board troubleshooting, alligator clip leads for a more permanent connection while monitoring circuit functions and mini-clip hooks for clipping on a pin of a component. You may be able to save a bit of money by standardizing on probe-type leads and then buying clip-type adapters to go on the ends. Flexible stranded wire makes for ease of use around many obstacles. Rubber insulation provides isolation up to 600 volts or more.

A good rule of thumb is, if the voltage you're measuring is high enough that you have to use the special high voltage input on the meter, you should be using special test leads.

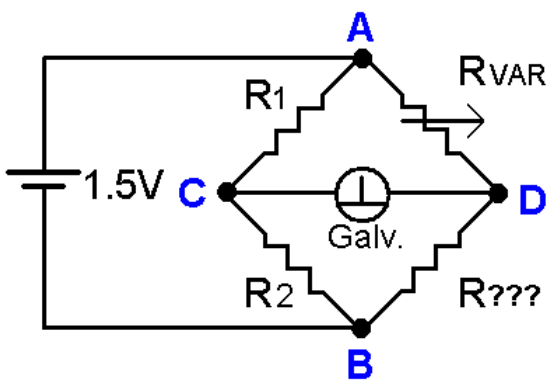
Some DMMs are so small they can be built right into the test leads. This at least partially solves the problem of tangled wires. When making a measurement, the display is almost always at an awkward angle for viewing, so measurement is made by placing the probe on the point to be measured, pushing the “hold” button, then removing the meter and looking at the result.

## RESISTIVE BRIDGE CIRCUITS

by Richard Booth

Resistive DC bridge circuits are frequently used in electronics. The most commonly used bridge circuit is the **Wheatstone Bridge** as shown below.

Notice that the bridge circuit is comprised of two circuits, each containing two resistive branches. The two circuits, the comparing circuit composed of $R_1$ and $R_2$ and measuring circuit composed of a variable resistor and an unknown resistance being tested, are joined together at points C and D by a **galvanometer**. A galvanometer is a d'Arsonval movement with a pointer that normally rests in the center, thus it can be deflected either way to show both magnitude and direction of current flow. To better understand how this bridge circuit works let’s look at each detail individually.



The comparing circuit includes two fixed resistive branches. Though these values are fixed, many bridge circuits incorporate the ability to substitute branches. This provision allows the technician to change the resistive ratios of $R_1$ and $R_2$ with respect to each other, which then enables various measuring ranges to be quickly achieved.

The measuring circuit also contains two branches. $R_{VAR}$ is used to bring the bridge into balance via a variable control. This variable control is often a potentiometer, which has the ability to provide a wide range of finely controlled variable current changes within the measuring circuit. It is provided with a carefully calibrated scale so the user can read its resistance with precision. The other resistor, $R_{???}$, is the unknown resistor whose value we want to find.

When voltage is applied to the bridge circuit by the battery, the galvanometer will react to differences in potential between points C and D. With no current flowing through the meter the needle will point to zero.

Wheatstone bridge operation is most easily understood if we assume $R_1$ and $R_2$ are equal. In this case, they will divide the battery voltage between them. If we take point B as zero volts, the voltage at C will be exactly half that at A.

To find an unknown resistance, we attach it across points D and B. Now $R_{VAR}$ and $R_{???}$ form another voltage divider. We adjust $R_{VAR}$ until the galvanometer pointer rests in the center, showing that there is no voltage between C and D. In this state it is said to be **balanced**. We know $R_1$ and $R_2$ are equal, thus dividing the voltage in half If there is no voltage between C and D then those resistors must also be equal. So, to find $R_{???}$ we simply adjust $R_{var}$ until the meter reads zero and then read the value of $R_{VAR}$ from its scale.

The Wheatstone Bridge is a clever application of the principle of the **null**. There are all sorts of problems associated with accurately measuring a voltage, but it's easy to measure whether two voltages are precisely the same. If the galvanometer is sensitive, the null can be very sharp. Accuracy depends only on the precision of $R_1$, $R_2$ and $R_{VAR}$. The DC voltage and galvanometer accuracy are irrelevant.

**Using a Wheatstone Bridge:** The Wheatstone bridge is usually a small portable device powered by a low voltage power source, such as a flashlight battery. When an external power source is used to power the bridge circuit, the user should make sure the source is set to the minimum voltage that will allow operation. Increasing the source voltage can cause uncompensated thermal variations, thus decreasing the bridge's accuracy. If greater bridge sensitivity is needed, and your bridge has the ability to change branches to achieve the appropriate sensitivity, then that solves the problem. If not, then use a galvanometer with greater sensitivity.

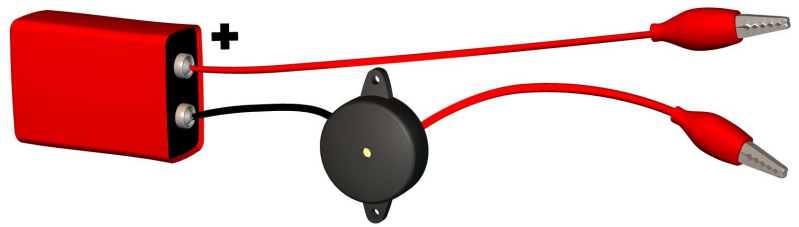
An important factor  is thermal agitation, which produces voltages that interfere with the galvanometer's reading, thus interfering with the balancing of the bridge circuit.  Direct sunlight can heat the resistors enough to throw off its accuracy.

One of the Wheatstone Bridge's strengths is its ability to accurately measure very low resistances.  When measuring a low resistance, confirm that the leads are tightened to the posts securely.  By ensuring the resistor leads are affixed to the bridge circuit's binding post in a secure manner, contact resistance can be kept to a minimum.  Any leakage paths, whether from the binding posts or resistor leads along the outside body of the resistor can, will result in a false galvanometer indication  Also, make sure that all solder joints, stranded wire leads, and lead connections are void of any defects or electrical anomalies.  If you have to use leads that connect the resistance under test to the bridge circuit, measure the lead resistance first and then subtract their ohmic value when you measure the resistor.

Bridge circuits are used in many ways beyond basic resistor measurement.  They can be used to precisely measure an unknown voltage, to manipulate control signals as well as for providing indications for test equipment.

## Continuity Tester

If there's an electrical path between one point and another, there's **continuity**.  A simple device to test for continuity can be built from a battery, a piezoelectric audio beeper  (e.g. Radio Shack part no. 273-059) and a pair of clip leads.  Add a switch and a box if you like.  This is essentially a crude ohmmeter, but the readout is sonic instead of visual.



Proper cable testing involves more than checking to be sure there's continuity between corresponding pins.  You also have to make sure there's *not* continuity to other pins – nothing shorted crosswise, in other words – and if the shell is metal, that there is no continuity between any pin and the shell (unless it's wired that way).  A complete test of a cable with connectors having 6 pins and grounded shells involves testing end to end in this manner (next page):

**Test pin 1 to: 1, 2, 3, 4, 5, 6, shell**
**Test pin 2 to: 2, 3, 4, 5, 6, shell**
**Test pin 3 to: 3, 4, 5, 6, shell**
**Test pin 4 to: 4, 5, 6, shell**
**Test pin 5 to: 5, 6, shell**
**Test pin 6 to: 6, shell**
**Test shell to: shell**

This test goes much faster with an audible tester than an ohmmeter, because you don't have to look at the meter every time. Of course, if your VOM has a continuity beeper built in, you're set.

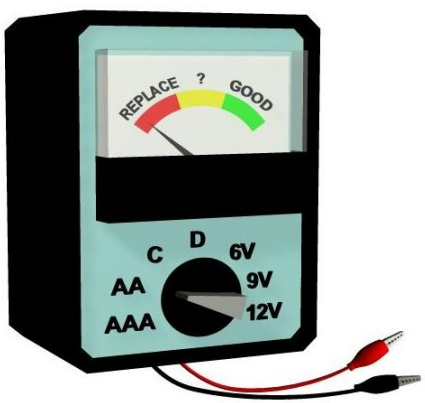
## Cable Tester

If you wind up working with cables a lot, you'll want to buy a dedicated tester. This has one LED for every pin on both ends. As you step through the test a pin at a time, continuity for each circuit is instantly shown, as well as any cross-circuit shorts.

The picture above right shows how the tester would indicate a defective cable – you'll just have to imagine there's actually a cable plugged into it. There is continuity from pin 2 to pin 2, but one of the ends also has a short between pins 2 and 6.

## Battery Tester

A battery tester is a voltmeter with switch positions calibrated to the most common battery voltages. Some meters also put a load across the battery, which is the best way to test.



## Resistor Substitution Box

Techs who do a lot of bench work often find it handy to have a box with a wide range of resistors, selectable by rotary switch. This allows a defective resistor to be temporarily replaced with another one of approximately the same value, so you can see if that's the only thing wrong with the circuit or if there's some other malfunction.

## Megger

A “megger” is used to test insulation in motors, transformers, etc. A high voltage is applied to the wire and a sensitive meter checks for any leakage between the wire and the rest of the unit. Earlier it was stated that there is no danger to a tech involved in making resistance measurements. This is an exception; meggers require care in use as their output is often on the order of 10kV.

Though “megger” is often used as a generic word, it is in fact a trademark of Megger Group Ltd.

***End of Chapter 9***

# EM1 Chapter 10
# BATTERY POWER SUPPLIES

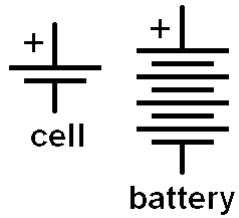
**by Karl Eilers**

*Objectives of this chapter:*

- *describe battery construction, chemistry and operation*
- *describe battery ratings*
- *compare characteristics of different kinds of batteries*
- *explain what happens when batteries are connected in series*
- *explain what happens when batteries are connected in parallel*

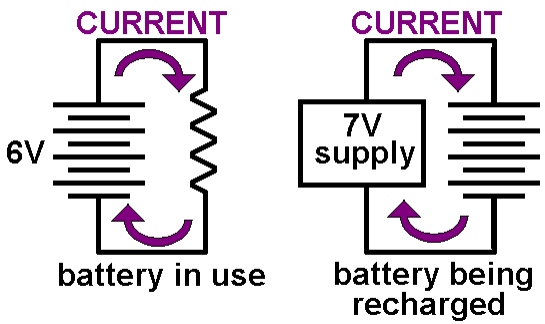
To recap what I said at the end of chapter 5: "A battery is usually thought of as a device that stores electricity. There is a device like that, but it's not a battery. It's called a capacitor, and we'll study it in EM2. A battery, on the other hand, *makes* electricity on demand from its store of chemicals. Its schematic symbol is a series of long and short lines; the end with the long line identifies the positive terminal."

Strictly speaking, an individual battery should be called a **cell**, whose schematic symbol is a single pair of lines, one long, one short. The term "battery " should be reserved for multiple cells wired in series. There is no such thing as a 1.5V "flashlight battery." But everybody misuses the term, and if you go around correcting them, they'll start giving you wedgies.




Cells are low-voltage devices. The most common generate around 1.5V DC. Where a higher voltage is needed, multiple cells are connected in series.

Batteries are broadly divided into **primary cells**, which are used up and then discarded, and **secondary cells**, which can be recharged. Batteries are recharged by connecting them to a higher-voltage DC source that forces current backwards through them, reversing the chemical process inside.



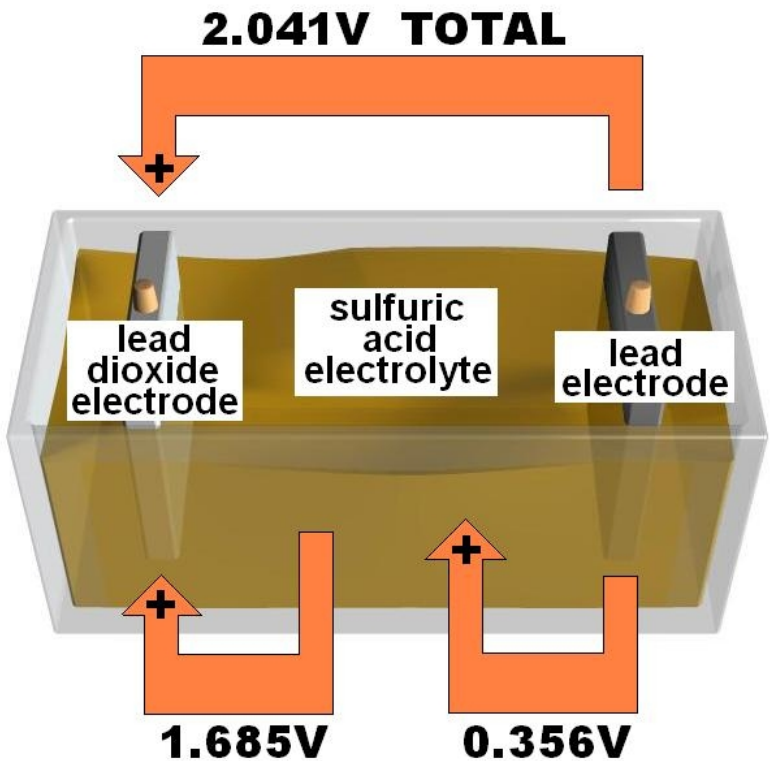

Electrically, a battery consists of two **electrodes** made of different conducting materials, both immersed in an electrically conductive chemical called an **electrolyte**.

One of the terminals is called the **anode** and the other is the **cathode**. Most people refer to the positive battery terminal as the anode, no matter what kind of battery it is, but in fact which terminal is which depends on the chemistry inside the battery. This essentially renders the terms “anode” and “cathode” useless where batteries are concerned. It's best to avoid confusion by speaking only of the **positive terminal** and the **negative terminal**.

## BATTERY CHEMISTRY

Batteries rely on the fact that when chemically different materials are brought in contact with each other, a chemical reaction often occurs which creates a voltage between the two materials. For example, a car battery consists of six cells where the electrodes are lead and lead dioxide, and the electrolyte is sulfuric acid. A lead-acid cell is shown to the right. In a perfect cell, the reaction between the acid and the lead dioxide electrode produces 1.685 volts, while the reaction between the acid and the lead electrode produces 0.356 volts. The two potentials add to produce a total voltage of 2.041V. A car battery's six cells, wired in series, add up to just over 12 volts.

In some other types of batteries, the two potentials don't add; one subtracts from the other. However, one potential is higher than the other by a large enough margin to provide a useful net output voltage.



LEAD ACID CELL

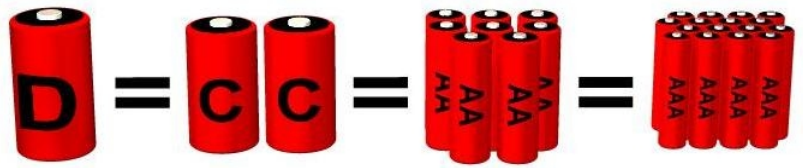
There are hundreds of different electrode and electrolyte combinations, but only a few that make worthwhile batteries. Despite their differences, the underlying mechanism is always the same.

When a battery sits idle, supplying no current, the chemical reactions proceed only far enough to create the voltage potentials, then they stop. When current is drawn from the battery, the reactions resume. Eventually, the reactions will run their course, all the chemicals will be morphed into other chemicals, and the battery will go dead.

At this point, in a primary battery, the chemicals and electrodes are so degraded that they cannot be recovered. In a secondary battery, forcing current backwards through the battery reverses the chemical reactions and de-morphs the materials back to their original state. The battery is then recharged and ready to be used again.

## BATTERY RATINGS

Battery capacity is rated in **Ampre-Hours**, which is the maximum load current the battery can supply times the number of hours it can keep doing it. A battery's amp-hour rating is determined by the type of chemistry and by its size. AAA, AA, C and D flashlight batteries all put out 1.5V, but a D cell can typically keep it up at least a dozen times longer than an AAA cell.




## COMMON BATTERY TYPES

### Carbon-Zinc

- primary battery (non-rechargeable)
- 1.5V
- lowest cost, not long-life

6V lantern batteries are four carbon-zinc cells in one package; 9V batteries are 6 cells in series. When cells are connected in series, the voltage is the sum of the individual cell voltages and the amp-hour rating is the same as for one cell. The materials are consumed as the battery delivers current, and a spent battery cannot be recharged. Also, a spent battery should be promptly removed from equipment because it is likely to leak corrosive fluids. The output voltage is approximately 1.5 volts per cell.

## Alkaline

- primary battery
- 1.5V
- amp-hour rating 3 to 8 times that of carbon-zinc

A few alkaline types are rechargeable up to 25 times.

## Lead-Acid

- secondary battery
- about 2.1V
- very high peak current capability
- hazardous waste

The oldest type of rechargeable cell, used in car batteries. When manufactured, both electrodes are pure lead and there is no potential across them. Charging turns one electrode into lead dioxide, which becomes the positive terminal. A car battery consists of 6 cells in series.

We think of lead-acid batteries as very brawny, but their energy-to-weight ratio is actually not nearly as good as most other types. Their advantages are a very high (dangerously high!) peak current capacity, the ability to be discharged and recharged hundreds of times, comparatively low price, and a well-established, mature manufacturing technology.

## Mercury

- primary battery
- 1.35V
- hazardous waste

Mercury batteries used to be popular for button cells used in hearing aids and the like. Because mercury is a hazardous material, and because better alternatives have been developed, mercury cells are becoming obsolete.

## Nickel-Cadmium or NiCd

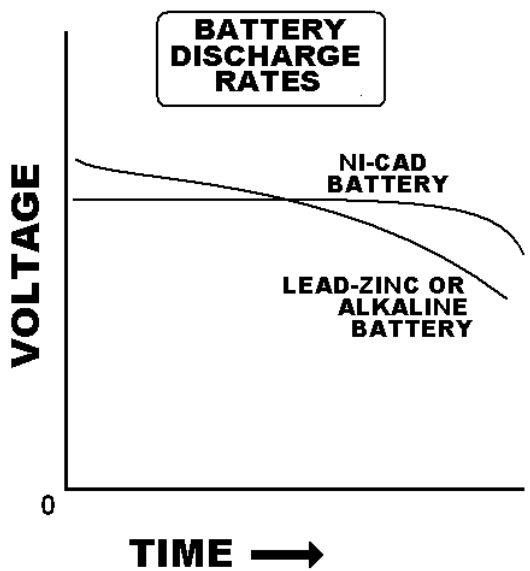
- secondary battery
- 1.2V
- requires smart charger or low charge current
- memory effect
- hazardous waste

A much better cell than carbon-zinc, also much more expensive but often worth the cost. Low internal resistance, with a resulting high peak current capability. Can be deeply discharged and recharged hundreds of times. 9V-sized batteries are usually 7.2V, but some manufacturers add a cell to make an 8.4V battery. Big NiCd batteries are much lighter than equivalent lead-acid batteries.

If a NiCd cell is not exercised, it will deteriorate to where it can't perform beyond the small amount of work it has gotten used to. This is called **memory effect**. To keep this from happening, a NiCd battery has to hit the gym now and then. It needs to be worked to its limits and completely discharged. It should be stored in a discharged state.

It's hard to say what typical amp-hour ratings are, because D-cell NiCd's are often C-size batteries in D-size cases!

The voltage across a NiCd cell does not change much between full charge and almost complete discharge. This makes it difficult to devise a meter to tell how much charge is left. It also makes it difficult to build a simple charger that knows when the cell is fully charged. Overcharging a NiCd, except at very low current, causes it to heat up dangerously, and a hot NiCd is a bomb waiting to go off.




There are three proper charging methods. One is to monitor the temperature of the NiCd cell. When it starts to heat up, that's full charge, and the charger shuts off. The second is to closely monitor, not the voltage across the cell, but the *rate of change* of voltage. There's a sudden, small voltage rise just as the cell reaches full charge. When the charger sees that, it shuts off. Either of these methods requires a "smart" charger. The third method is to simply charge the cell slowly, at about $^{1}/_{10}$ its amp-hour rating. A full charge by this method may take as long as 12 hours.

Cadmium is very poisonous to humans, so dead NiCd batteries should be treated as hazardous waste.

## NiMH

- secondary battery
- 1.2V
- requires smart charger or low charge current
- should never be completely discharged
- 2 to 3 times amp-hour capacity of NiCd

An improvement on NiCd cells, having similar characteristics but using a metal alloy instead of cadmium, which eliminates the environmental hazard.

NiMH cells do not have NiCd's memory problem. The cells should never be discharged below 1V, especially when series-connected in battery packs, or they will be ruined. An automatic low-voltage cutoff is included in many things that use NiMH batteries. They require “smart” chargers.

NiMH batteries are replacing NiCds in things like portable hand tools. NiMH batteries should not be recharged in NiCd chargers; the end-of-charge indicator is a slight sag in voltage, which is opposite from NiCd batteries.

### Lithium-Ion or Li-ion

- secondary battery
- up to 3.7V
- high power per cubic volume
- requires smart charger or low charging current

A different chemistry, using a lithium salt as an electrolyte. For a given power density, smaller and lighter than other types, making them highly desirable for hand tools, cell phones, notebook computers etc. They're getting a slow start in the USA, but in Japan, 2/3 of all batteries sold are already Li-ion. All my hand drills are old NiCd types, and every time I use a Li-ion drill, I'm surprised at how much work it can do before the battery runs down.

Li-ion batteries absolutely require smart chargers; trickle-charging doesn't work well. I won't try to say anything more specific because Li-ion technology is developing so rapidly that anything I say would soon be obsolete.

## COMPARISON OF RATINGS

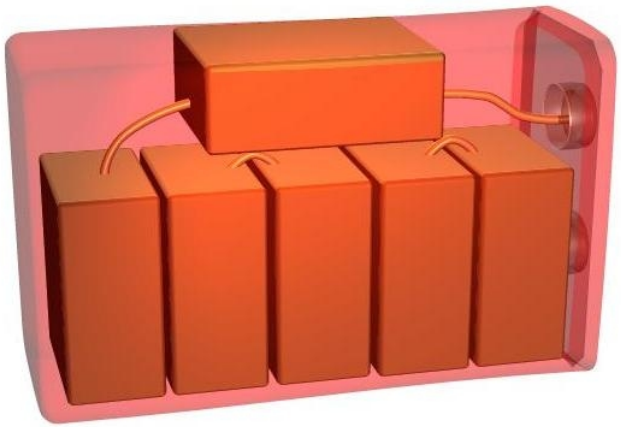
For a typical AA cell, the amp-hour ratings of various types are as follows. These ratings are useful to determine how long a battery will last with a certain current draw. However, as comparisons of energy storage, they're misleading because the voltages are different. So I've also listed energy storage in joules. Allow for lots of variation among manufacturers. Note that lead-acid batteries are not made in the AA size.

| | | |
|---|---|---|
| ● Carbon-zinc | 1.1 A-h | 2,300j |
| ● Alkaline | 3 A-h | 9,400j |
| ● NiCd | 0.5 -1 A-h | 4,300j |
| ● NiMH | 1-3 A-h | 9,000j |
| ● Li-ion | 0.9A-h | 1,1000j |

You may note that when comparing batteries with the same voltage, the A-h and joule ratings aren't always proportional as they should be. This has to do with the ways batteries are measured and how they differ between, for example, light and heavy loads. That's one reason the numbers should be regarded as approximations.

## CELLS IN SERIES

As already mentioned, when cells are connected in series, their voltages add. You've probably inserted four or six AAA cells in a radio to get 6 or 9 volts. Higher-voltage batteries are simply series-connected cells in one package. For example, a 9V alkaline battery is six 1.5V cells in a single package.



The combined amp-hour rating of identical cells in series is the same as for a single cell. They should discharge at the same rate, but if one cell is weak, it will discharge faster. That's one reason NiMH batteries can't be allowed to discharge below 1V/cell; if there is one weak cell, it would discharge to zero when there was still energy in the other cells. From that point, as the other cells continued to supply energy, the weak cell would become reverse-charged, which would ruin it.

## CELLS IN PARALLEL

Cells in parallel are about equivalent to a single larger cell. The voltage stays the same, but the amp-hour capacity adds. Two AAA cells in parallel are about the same as an AA cell; four AA cells are about the same as a C cell; two C cells are about the same as a D cell.

***End of chapter 10***

# EM1 Chapter 11
# MAGNETISM

**by Richard Booth**

*Objectives of this chapter:*

- *Explain basic magnetic properties*
- *Describe the properties of magnetic materials*
- *Explain fields and lines of force*
- *Explain magnetomotive force*
- *Explain the relationship between electricity and magnetism*

***Editor's note: why is there a chapter about magnetism in an electronics study guide? Because magnetism is involved in so much of what electronic technicians do. In fact, if we were to get into theoretical physics, we would see that magnetism and electricity are so closely connected that physicists now refer to magnetism and electricity as a single science, "electromagnetism."***

Magnetism is called "the invisible force." Of course, electric charges push and pull on each other at close range, but magnetism acts more strongly over a greater distance. Your first observation of magnetism was probably the common horseshoe-shaped silver and red magnet. You may recall its ability to attract iron filings or pick up small metal objects. Another device that uses magnetism is the compass. With its magnetized needle, it is always easy to see which direction is north. These two examples demonstrate that, though we cannot see them, magnetic fields are all around us. It is the fundamental force that enables the operation of electric generators, motors, and many other types of electrical and non-electrical equipment.

## MAGNETIC AND NONMAGNETIC SUBSTANCES

A **magnetic** substance is one which is attracted by magnets, and which can be **magnetized**; that is, it can be made into a magnet. A **nonmagnetic** substance cannot be magnetized and is not affected by magnetism. From the standpoint of magnetism, nonmagnetic substances are ghosts: magnetic fields pass through them as if they were not there. Most things like glass, plastic, wood and paper are nonmagnetic.

Some "nonmagnetic" materials are not completely nonmagnetic. Aluminum, manganese, chromium and many other materials, even water, can become weakly magnetized. But the magnetization is so weak that it is considered useless in the realm of magnetism and these materials are classed as nonmagnetic.

## NATURAL AND ARTIFICIAL MAGNETS

Despite the speed with which advancing technology is turning science fiction into science fact, at least one thing is still the same: iron remains the only material that can exist as a magnet in its natural state.

**Natural magnets**, magnets found in nature, are quite rare and usually quite weak. A black iron ore called **magnetite** is a natural magnet. One of the earliest accounts of magnetite being used is for navigation. The Chinese learned that if a piece of magnetite stone was mounted in a free spinning horizontal plane the stone would always orient itself in a particular direction. This was the first known magnetic compass. Oddly enough, the ancient Chinese made their compasses to point south. Because of magnetite's ability to always point in one direction, it became known as a leading stone, or lodestone.

**CHINESE COMPASS**

Natural lodestones' magnetism is weak and unstable. Fortunately, we've learned to make magnets with a much stronger magnetic field, which are known as **artificial magnets.**

The first artificial magnets were produced by touching a piece of iron to magnetite. It was later discovered that during the forging process an iron bar could be magnetized by placing it in alignment with the magnetic field of the earth. In today's manufacturing process, artificial magnets are developed by placing a piece of magnetic material in a magnetic field produced by an electrical current. These magnetized metallic objects are manufactured in a variety of sizes and shapes, and are not only used to attach something to a refrigerator, but also in a considerable array of electronic devices as well.

## TEMPORARY AND PERMANENT MAGNETS

Some magnetic materials are difficult to magnetize; they require an extremely strong external field to turn them into magnets. However, once they are magnetized, they stay magnetized. These are called **permanent** magnets. Other materials are easy to magnetize but lose their magnetism as soon as the external magnetizing field is removed. These are called **temporary** magnets. Neither is better than the other; we have uses for both.

Iron which easily acquires and loses magnetization is called **soft iron.** Iron which is hard to magnetize but retains its magnetization is called **hard iron**. These terms do not refer

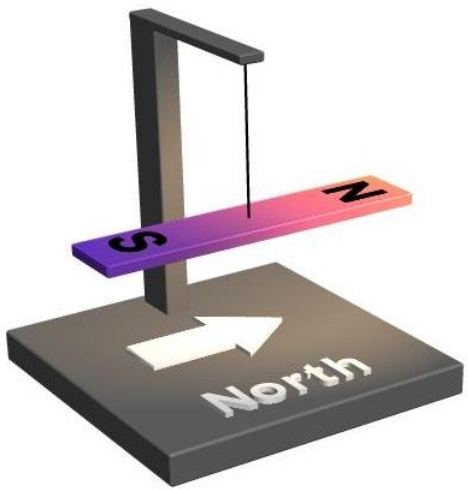
to the physical hardness of the material – even the softest iron is physically hard – but to the ease with which they become magnetized and demagnetized.

When you touch a piece of soft iron to a magnet, it becomes temporarily magnetized. It is then called an **induced** magnet. Loudspeakers and disc drives among other devices use induced magnets to convey magnetism from a permanent magnet to where the magnetism is used.

By combining other materials such as nickel and cobalt with iron, stronger magnets can be made than with iron alone. Some exotic materials developed in the last few decades can make magnets so strong you can get your fingers crushed between them if you're not careful.

## MAGNETIC POLES

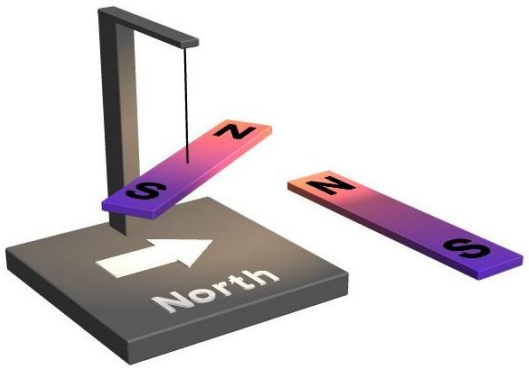
Imagine a bar magnet with one end orange and the other blue. Suspend this magnet so it is free to rotate. If you give it a spin you will observe it slowly coming to rest with one end pointing in a northerly direction. Repeat this action, and you'll notice the same end of the magnet will come to rest pointing north every time. This indicates that magnetism is concentrated at the two ends of the bar magnet, thus defining them as **poles**. The north-seeking end is named the **North pole** and the south-seeking end is named the **South pole**.



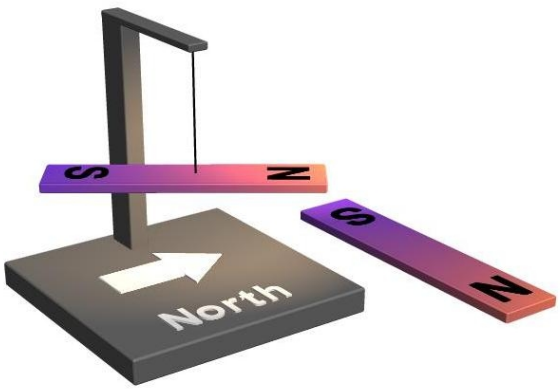

***Ed. note: in these study guides, to avoid confusion between electric charges and magnetic polarities, the electric charges of subatomic particles are shown as red and green, while magnetic polarities are shown as orange and blue.***

The two poles, though opposite in polarity, are equal in magnetic strength. In this way they resemble electric polarities. However, there is no such thing as an isolated magnetic pole; every magnet has both a North and a South pole. If you take a magnet with its two poles and break it into little pieces, each piece will have both a North and a South pole.

Taking the newly designated North and South pole bar magnet, let's introduce a second bar magnet and observe what happens. If the two North poles are brought near each other, the North pole of the suspended magnet moves away. However, if the South pole of the second magnet is brought near the North pole of the suspended magnet, the poles will move toward each other.




**LIKE POLES REPEL**



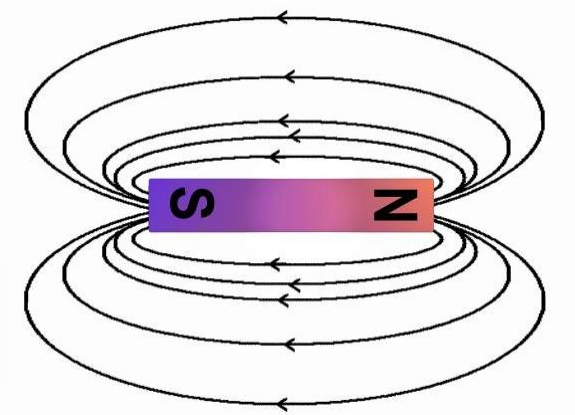

**UNLIKE POLES ATTRACT**

This action shows the basic law of magnetism, which states that **like poles repel** while **unlike poles attract** – just like electrical charges.

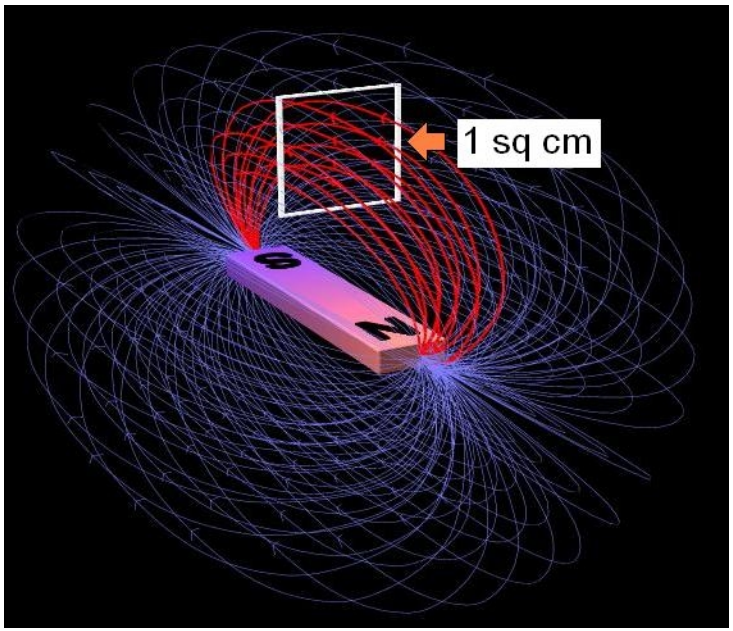
Since a magnet's North pole points to the Earth's North Pole, doesn't that mean the Earth is a big magnet – and its North Pole is actually a magnetic *South* pole? Yes, it does.

## MAGNETIC FIELDS

The fact that magnets can act on each other and on nonmagnetized magnetic materials at a distance means that magnets have fields. At every point in the space surrounding the magnet, the field has both an intensity and a direction. This is commonly illustrated by drawing **magnetic lines** which travel *from* the North pole *to* the South pole, and back through the magnet to the North pole. These lines of force completely surround the entire magnet flowing in and around its entire length. The number of lines in a particular area show the strength of the field. The arrows show the direction.

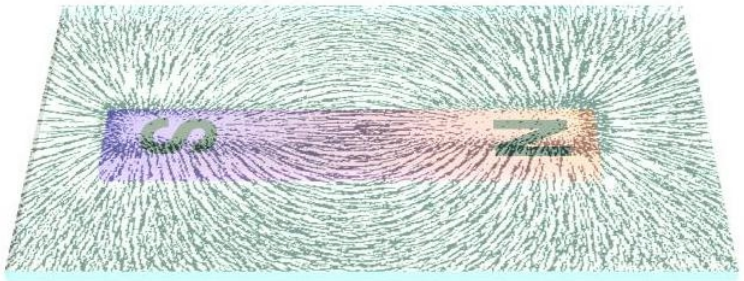


The total number of lines of force which occupy the space in and around the magnet is called **magnetic flux**, while the number of lines passing perpendicularly though one square centimeter of a field is called **flux density**.




**FLUX DENSITY**

Magnetism is, of course, invisible. But we can make the field visible by placing a magnet beneath a piece of glass and sprinkling iron filings on the glass above and around the magnet. If we tap on the glass to agitate the filings, they will arrange themselves into a definite pattern as in the illustration below. This pattern is a visual representation of the bar magnet's field.



It should be understood that “magnetic lines” are fictional. Even very knowledgeable people are often confused on this point. The misunderstanding probably arises from the way the iron filings arrange themselves into strings, which is actually caused by the fact that induction has turned them into tiny magnets which repel and attract each other. It's reinforced by the expression, “cutting through the lines of force,” which is an imprecise way of describing what happens when a field moves across an electrical wire. In reality, a magnetic field is not separated into lines but is continuous, smoothly and gradually varying in strength from one point to another. We use lines and arrows to show this field because nobody has invented a better way of showing a field's shape, its direction, and how its strength varies with distance from the magnet.

## THEORY OF MAGNETIZATION

There is disagreement about how magnetization occurs at a molecular level. The two most popular theories agree that a magnetic material is made of tiny bar magnets. In one theory, the bar magnets, called **domains**, are molecules. They point in all directions when the material is unmagentized, but physically flip to line up in one direction when the material becomes magnetized. In the other theory, magnetization occurs at the subatomic level. Electrons spin in different directions, so the magnetic fields they generate are canceled out, but in the presence of an external magnetic field, some electrons change their spin, and the material becomes magnetized. In either case, magnetization and demagnetization occurs a step at a time. It is even possible, under some conditions, to arrange an external sensor so you can hear these steps occurring.

## PROPERTIES OF MAGNETS AND MAGNETIC MATERIALS

There are a number of terms that describe various aspects of magnetic materials. If you actually work with these factors, you'll get special training, but even if you don't you should know what they mean.

**Permeability** is the degree of magnetization that occurs in a material in response to an external magnetizing force. Put another way, the term describes how easy it is for a field to find a path through the substance. Air has a permeability of 1; some kinds of iron have a permeability of 10,000. This means a magnetic field will find a path through iron 10,000 times more easily than through air.

**Reluctance** is the reciprocal of permeability; the higher the reluctance, the stronger the external field required to magnetize the material.

**Saturation** is the condition where all the material has been completely magnetized. Increasing the strength of the external field will not cause the material to become more magnetized. The domain theory says saturation occurs when all the domains are lined up in the same direction; it is impossible for the material to be more strongly magnetized than this. The only way to make a stronger magnet is to choose a different material with more strongly magnetized domains.

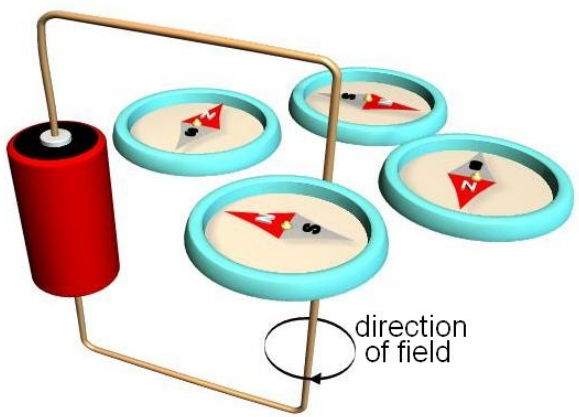
**Retentivity** or **residual magnetism** is the amount of magnetization that remains after the external magnetizing field is removed. A permanent magnet would have high retentivity.

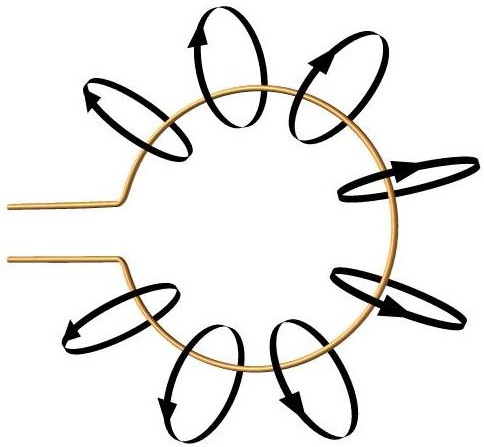
**Coercivity** is how strong a reverse external field must be to return a piece of magnetized material to zero magnetization.

## ELECTROMAGNETISM

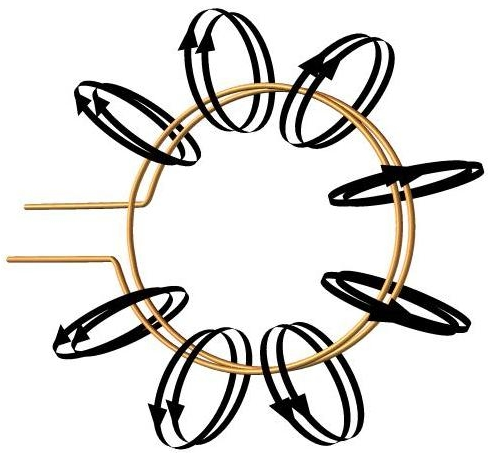
Any time an electron moves, a magnetic field is created. Zooming out from the micro world to the macro world, we can state the principle that an electrical current always develops a magnetic field.

Suppose you connect a wire across the terminals of a battery. By now you'll recognize that as a short circuit, so we'll use a wimpy carbon-zinc AA cell with enough internal resistance to limit current to a safe value. If you use a compass to sniff out the magnetic fields near the wire, you'll find that there's a field that completely surrounds the wire, with lines of force that run at right angles to the wire. This is a basic principle of electromagnetism: the magnetic field is perpendicular to the current that created it.



Now let's make the wire into a loop. We've just given the field a form, similar to the field of a bar magnet, and created an **electromagnet**. The strength of the field depends on the strength of the current flow; more current, stronger field.



Let's add a second loop – what do you think will happen to the magnetic lines and magnetic field strength? It will be stronger than before, since the lines of force of the two loops are combined. Thus the strength of the field also depends on the number of loops.

Note that we're using copper wire, a nonmagnetic material. An electromagnet does not depend on magnetic materials because the magnetism is not caused by the material but by current. Even electrons shooting through space generate an electromagnetic field.

When we form a wire into multiple loops, we make a **coil**, like a coil of rope. Each loop is called a **turn**. The property that creates a magnetic field is called **magnetomotive force**, which does not describe the push or pull of a field on another magnet or piece of magnetic material but the force that *creates* the field, just as electromotive force creates current flow. However, since the field it creates is what pushes or pulls on magnetic materials or other fields, the two are closely related.

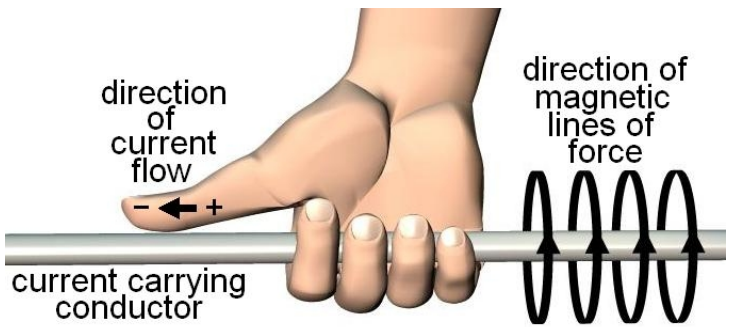
Since magnetic force depends on current flow and number of turns, we can write an equation:

$$F_M = NI$$

where $F_M$ is magnetomotive force in amp-turns, N is the number of turns, and $I$ is current.

## DIRECTION OF MAGNETIC FIELD

What is the relationship between the direction of current and the direction of the resulting magnetic field? That's often important to know. Here's a simple memory aid. It's called the **right hand rule** and it's used with conventional current, flowing from positive to negative. If you grasp the conductor with your right hand so your thumb points in the direction of current flow, your fingers will wrap around the conductor pointing in the direction of the magnetic field.




**RIGHT HAND RULE (CONVENTIONAL CURRENT)**

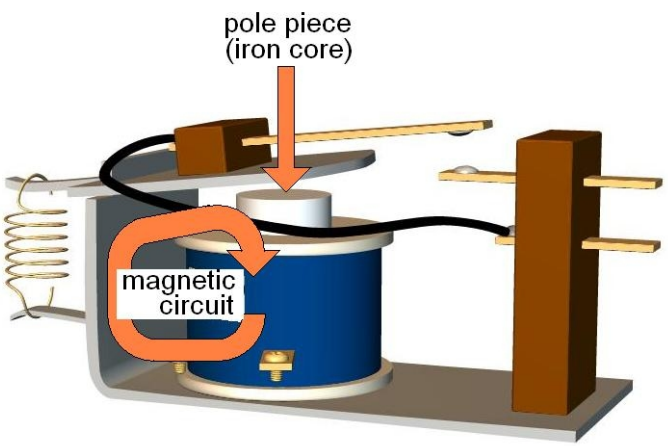
When we're talking about actual electron flow, from negative to positive, use the left hand.

For a coil, since current is flowing through all the turns in the same direction, wrapping your hand around the entire bundle, with your fingers through the hole in the middle, will give the same result.

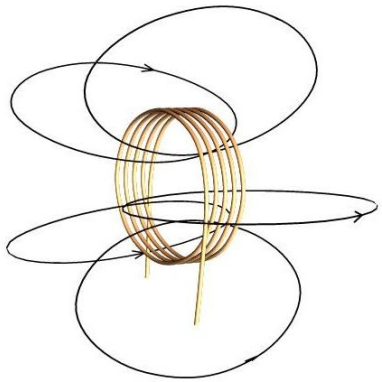
## COMBINING ELECTROMAGNETISM AND MAGNETIC MATERIALS

by Karl Eilers

Now it's time to put magnetic materials and electromagnetism together. At any sane current level, the field generated by a wire is very weak. If the wire is coiled up, the field will get stronger but still won't be strong enough for many of the things we like to use electromagnets for. The field can be strengthened by adding more turns, but that either means a very large diameter coil with more wire in it, or thinner wire. Either option will increase resistance and limit current, and a point will be reached where losses offset gains. For this reason, the simple electromagnets we've been discussing are of limited use. However, there's a way to make a much stronger magnet with a reasonable current, and you've already run across it once.

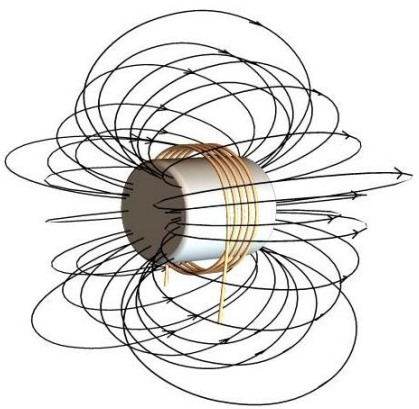



In chapter 5, we discussed relays, and we saw that the coil had a chunk of metal in the middle, called a “pole piece.” Why was it there? Why wasn't the coil alone sufficient to move the armature? Because a coil without a pole piece is a weak magnet.

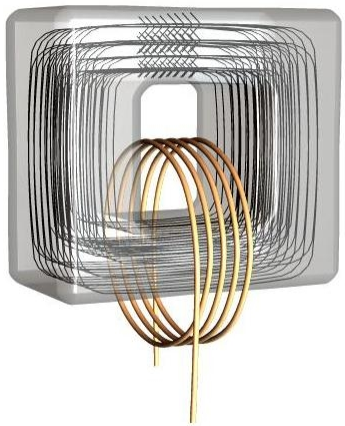


air core-
weak magnetization

We've seen that permeability is different for different materials. Air is used as the reference; it has a permeability of one. Soft iron, on the other hand, has a permeability on the order of 10,000. If we put a piece of soft iron in the middle of a coil, we'll get a much stronger magnetic field for the same amount of current. The material in the center of a coil is called the **core**. We've been studying **air core** magnets and now we're going to look at **iron core** magnets.



soft iron core -
strong magnetization



complete magnetic circuit - very strong magnetization

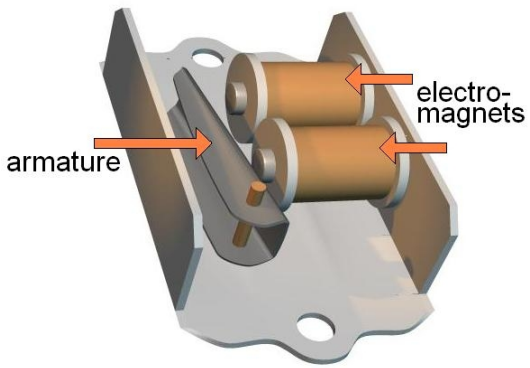
The most efficient arrangement is a complete magnetic circuit, which is similar to an electrical circuit. Soft iron in a square shape with a hole, or sometimes a donut shape (called a **torus**) provides a path for lines of force to travel completely within a high permeability material. In the illustration above, the iron core has been made partially transparent to show the lines of force within.

The problem is, with this arrangement we can't get at the field to make use of it. However, there is a class of components where a signal is magnetically transferred between two coils, which we will study in EM2, that makes use of a continuous magnetic path of this kind.

Still, if we just put some soft iron in the middle of the coil, we'll get a magnet that's many times stronger than one without. A relay's pole piece is made of soft iron, and that's what makes the electromagnet strong enough to do its job with a reasonable coil current.

It helps if a component can be designed to get as close as possible to a closed magnetic circuit. The relay is designed that way; note that the frame, which is iron, attaches to the bottom of the pole piece and travels up the side, where it contacts the armature. This conveys the magnetic field, forming almost a closed circuit, especially when the relay is activated and the armature pulls in.

Another way this is done is to use two coils and two pole pieces. Here is an illustration of the Edwards buzzer that's been manufactured for upwards of a century. Note that there are two coils and two pole pieces.




The coils are connected so current flows in opposite directions through them, meaning that the pole pieces are oppositely magnetized. The two pole pieces and their mounting create a U-shaped field; together with the armature they form a complete magnetic circuit. This “magnetic circuit” business is a basic principle of good magnetic design, not only with magnets but with motors and other devices.

## MAGNETIC ATTRACTION VS. DISTANCE

You probably know that magnetism pulls harder on nearby objects than on more distant ones. There's a specific function for that, which is simple in principle but complicated in practice. There are all sorts of factors like the shapes of the magnet and what it's attracting that need to be taken into account. “Field theory” is one of those classes that schools use to weed out students who can't cut it.

But if we're satisfied with a general rule and don't insist on precision, it's pretty simple: the relationship between pull and distance is an inverse square function. “Inverse” because increasing the distance decreases the pull. “Square” because if you double the distance between two magnets, or a magnet and a piece of iron, you'll get ¼ as much pull; triple the distance and you'll get $^1/_9$ as much pull and so on. In other words, a small change in distance makes a big change in pull. For this reason, engineers try to design equipment so magnets work at close range.

## SOLENOIDS

Sometimes magnets are designed so the space where the core should be is empty, and the armature is pulled right into the coil. This is called a **solenoid**. It partially overcomes the inverse square problem; a solenoid has a more gradual distance-vs-pull curve and it's used where the armature must move a comparatively long distance. A washing machine typically has several solenoids to operate valves and clutches.

A solenoid may be used in a relay that must carry very high current or voltage, where the contacts have to open a long way to prevent arcing. One common example is the starter solenoid in a car. A solenoid relay used with high power AC equipment is often called a **contactor**.

## FLYBACK

If a circuit with an electromagnet is suddenly opened, the coil will generate a very high voltage spike called a **flyback**. We won't study it here, because understanding the physical mechanism requires knowledge of AC and fixing the problem involves components we won't meet until EM2. But I thought I should call it to your attention, because lots of electromagnets operate on DC and flyback suppression is a basic requirement of good equipment design, especially around sensitive digital circuitry. On the other hand, flyback can be useful. Spark plugs in cars, igniters in stoves and furnaces, CRT monitors, xenon flashtubes and many other things make use of the flyback phenomenon. There's a whole subchapter on it in EM2.

***End of Chapter 11***

# CHAPTER 12 – EM1 REVIEW

***These pages are in a printer-friendly format because we want to encourage you to print them out and go over them until you can describe each of these items in your own words, which is similar to what you'll be asked to do when you take the exams for ETA certification. The various charts and tables from all the chapters are reproduced at the end of this chapter, and you should print those out too so you'll have them handy.***

***These pages are good for more than just test-taking. You should keep them around and read over them now and then to remind yourself of some things you may have forgotten. I would especially recommend regular review of the safety and math chapters.***


| CHAPTER | | PAGE |
|---|---|---|
| 1 | Basic Electricity | 2 |
| 2 | Safety | 5 |
| 3 | Math | 10 |
| 4 | Ohm's and Watt's Laws | 15 |
| 5 | Electronic Components | 16 |
| 6 | Series Circuits | 19 |
| 7 | Parallel Circuits | 21 |
| 8 | Series-Parallel Circuits | 22 |
| 9 | Meters and Measurements | 22 |
| 10 | Battery Power Supplies | 24 |
| 11 | Magnets | 26 |
| --- | Charts and Graphs | 28 |

## CHAPTER 1 – BASIC ELECTRICITY

Here's a brief recap of each of the words on the word list. There's also a chart of most commonly used units. It would be a good idea to print this out and keep it in your notes. While you're at it, you may find it convenient to print out the quiz that follows and mark the answers on paper.

**CHARGE** – the property that causes objects to electrically attract or repel other objects. There are two types of charge, **positive** and **negative**. An object which has no charge is **neutral**.

**ELECTRICITY** – the presence and movement of electrical charges.

**FIELD** – the area of influence surrounding a charged object that acts upon other objects at a distance. Charged objects repel other objects with the same charge and attract other objects with opposite charge. Charged objects also attract neutral objects.

**ATOM** – the smallest complete particle of matter. All objects are made of atoms. According to the Bohr model, an atom consists of smaller subparticles called protons, neutrons and electrons.

**ELEMENT** – a material made up of individual atoms of a single kind.

**PROTON** – the positively charged type of particle at the center of an atom. The number of protons determines the type of element – iron, copper, oxygen etc.

**NEUTRON** – the non-charged or “neutral” type of particle at the center of an atom. Neutrons add mass but usually are not involved in electricity. Neutrons and protons together make up the nucleus of an atom.

**ELECTRON** – the negatively charged particle that revolves around the nucleus. Its charge is equal but opposite to the proton's charge, but its mass is only about 0.05% of the mass of a proton or neutron. In a normal atom the number of electrons equals the number of protons; thus the atom has no overall charge. In most cases, it is electrons that move from place to place to create what we call electricity; protons do not move from atom to atom.

**ION** – an atom where the number of electrons is not equal to the number of protons; thus the atom has an overall charge.

**DISCHARGE** – what happens to a charged object when electrons flow in or out to neutralize its charge.

**MOLECULE** – a chemical particle composed of two or more atoms. The atoms can be the same element, or more often, different elements. When a molecule consists of different kinds of atoms – e.g. water, which is hydrogen and oxygen – it is called a **compound**.

***Review page 2***

**POLARITY** – describes the charge on a proton or electron, i.e. positive or negative polarity. Also describes the direction of charge difference between two points, i.e. which point is more positive or negative than the other.

**POTENTIAL** – the difference in polarity and strength of charge between two points. Charge is an absolute quantity; potential is a differential quantity.

**CONDUCTOR** – an element or compound in which some electrons can move freely from one atom or molecule to another.

**INSULATOR** – an element or compound in which all electrons are bound to specific atoms or molecules, and cannot normally move from one to another.

**SEMICONDUCTOR** – an element or compound whose conductive properties are dependent on specific chemical composition, how the material is made and operating conditions.

**STATIC ELECTRICITY** – electricity characterized by stationary charges on objects.

**CURRENT ELECTRICITY** – electricity characterized by the continuous flow of charged particles, usually electrons.

**CURRENT** – the flow of electricity; at an atomic level, the mass movement of electrons. The mathematical symbol for current is **I** for "intensity" of electron flow.

**AMPERE** – the basic unit of measure of current, abbreviated "amp" or **A**.

**ELECTROMOTIVE FORCE** – abbreviated "EMF," the force which causes electrons to move; at an atomic level, it is the electrical fields of protons and electrons acting on each other. The mathematical symbol is **E**.

**VOLT** – the basic unit of measure of EMF, abbreviated **V**. In common usage, most people say "voltage" instead of "EMF." In math, "E" is usually used when dealing with static electricity and "V" is used with current electricity, to denote that we're dealing with a differential quantity.

**RESISTANCE** – interference with the flow of electrons, an electrical kind of "friction." Even the best conductors have some resistance, except at temperatures near absolute zero. The mathematical symbol for resistance is **R**.

**OHM** – the basic unit of measure of resistance, denoted by the Greek letter Omega, **Ω**.

**RESISTOR** – an object deliberately made to have significant resistance.

**POWER** – the rate at which energy is consumed or converted from one form to another. Electrical power is voltage times current. The mathematical symbol for power is **P**.

**WATT** – the basic unit of measure of power, abbreviated **W**.

***Review page 3***

**JOULE** – power over time; one watt consumed or converted for one second, also called a **watt-second**.

**DIRECT CURRENT** – abbreviated **DC**, current which flows in one direction. A battery produces DC.

**ALTERNATING CURRENT** – abbreviated **AC**, current which alternates direction, constantly switching back and forth. An electrical power outlet supplies AC.

**CIRCUIT** – a path for current to flow in a continuous loop, usually including a power source, wires, and components such as lamps, motors and so on.

**SERIES CIRCUIT** – a circuit in which all the current flows in a single path through every component in succession.

**PARALLEL CIRCUIT** – a circuit in which there are multiple current paths, with some of the total current flowing through each path at the same time.

**SERIES-PARALLEL CIRCUIT** - a circuit combining the characteristics of series circuits and parallel circuits.

**CLOSED CIRCUIT** – a conductor arranged in a continuous loop in which current can flow.

**OPEN CIRCUIT** – a circuit which has been broken, preventing current from flowing.

**SHORT CIRCUIT** – a circuit with a very low-resistance path that shunts current directly across the power source, preventing electricity from reaching its intended destination and often resulting in excessive current.

**SWITCH** – a device which allows the user to conveniently create a closed or open circuit as desired.

**MAKE** – describes a switch closing.

**BREAK** – describes a switch opening.

**POSITIVE CURRENT CONVENTION** – a mental convenience in which current is imagined to flow from positive to negative, as opposed to actual electron flow which is from negative to positive.

**GROUND** – a common electrical reference for all the circuitry in a system, against which all voltages are measured. “Ground” is defined as zero volts, whatever its absolute charge may be.

**EARTH GROUND** – a ground electrically connected to Earth.

***Review page 4***

**EQUIPMENT or SYSTEM GROUND** – a ground reference within a system, which may or may not be Earth-grounded.

**COMMON** – another term for ground, especially if it also serves as the reference for the system power supply. A car's frame is the negative common for the whole electrical system.

**RAIL** – a conductor which connects various parts of a circuit together, especially a power supply or ground conductor. An ideal rail would have zero resistance, so it is electrically equivalent to a single point.

## CHAPTER 2 – ELECTRICAL SAFETY

**SAFE VOLTAGES** – in the USA, regulatory agencies consider 50VDC, 30VAC and 12V AC or DC in wet environments the maximum voltages that can be handled without significant risk of electrocution.

**MUSCLE FREEZING** – occurs when current through a muscle is 0.02A or greater. This can make a shock worse by preventing you from withdrawing your hand.

**ELECTROCUTION** – occurs at a current of about 0.1A.

**FIBRILLATION** – when the heart stops beating and goes into a trembling motion that does not pump blood. This can be triggered by an electric shock where current passes through the heart.

**AC HOT WIRE** – in a building wiring circuit, the wire that delivers current to an appliance.

**AC NEUTRAL WIRE** – the return wire for that current. Connected to Earth ground.

**AC GROUND WIRE** – connects the metal frame of an appliance to Earth ground. Connected to the neutral only at the point where power enters a building.

**AC WIRE COLORS** -

- Hot – most commonly black, often red or blue, sometimes other colors as needed for the number of circuits in a particular place.
- Neutral – white.
- Ground – green.

These colors are not to be trusted; electricians make mistakes. The technician should carry a power line tester.

**HOT CHASSIS** – a piece of equipment where one side of the power line is connected directly to the chassis. A non-hot chassis may become one through failure of the **hash filter** capacitor.

***Review page 5***

**HOT CHASSIS RULE** – before working on a piece of equipment, unplug the unit and measure from both sides of the plug to the chassis. You should get an open circuit.

**POWER DOWN RULE** – if possible, equipment should not be worked on while it's “live.” Disconnect all power wires. Removing a fuse or turning of a switch often leaves parts of the circuits hot.

**PHANTOM VOLTAGE** – the voltage stored by capacitors even after the unit has been unplugged.

**DISCHARGING** – using a wire to drain off phantom voltage. The wire should briefly be connected between each capacitor terminal and the unit's chassis ground – not Earth ground. Use of a special discharge wire with a resistor in it is recommended.

**VOLTMETER RULE** – before you start working on a piece of equipment, measure from various points in the circuit to chassis ground with a voltmeter to verify that power supply capacitors have been discharged.

**GROUND FAULT INTERRUPTER** or **GFI** – an outlet that senses an imbalance between outgoing and return currents and disconnects the circuit. A GFI does not depend on having a green-wire ground circuit to protect the user.

**IS0LATION TRANSFORMER** – usually a piece of bench test gear, electrically isolates a unit under test from the power line. This eliminates one kind of electrocution risk.

**POWER LINE TESTER** – a plug-in device that tests a power outlet to determine whether it's wired correctly.

**CIRCUIT BREAKER RULE** – don't turn off a circuit breaker and assume somebody else won't turn it on again, unless you can see the breaker from your work position.

**INVERTER** – a circuit that takes a safe low voltage and converts it to a higher, often unsafe voltage. A device with an inverter cannot be assumed to be safe just because it runs on low-voltage batteries.

**ELECTROCUTION THROUGH THE AIR** – electricity can leap through the air when the potential reaches about 10,000V per inch of dry air.

**VACUUM TUBE RULE** – any piece of equipment with vacuum tubes always contains dangerous voltages. Keep in mind that a CRT display is a vacuum tube.

**TOOL INSULATION** – use only pliers and cutters with insulated handles. Put heat shrink tubing on screwdriver shanks.

**ONE HAND RULE** – whenever you're working around high voltages, work with only one hand. Keep the other one in your pocket.

***Review page 6***

**BUDDY RULE** – don't work alone. Make sure there's someone else around and that you're in their line of vision.

**WIRE GAUGE** – thickness of a wire; smaller numbers indicate larger diameter. For each wire gauge there is a maximum safe current. In building wiring, 14ga. wire is safe to 15A, 12ga. to 20A. This can be taken as a rough guide to AC or DC wiring anywhere in a system, though the National Electrical Code has specific guidelines for specific situations.

**FUSE** – an undersized wire, contained in a small enclosure, that's designed to melt and open a circuit before the rest of the system overheats and starts a fire. Fuses are rated by current.

**CIRCUIT BREAKER** – essentially a resettable fuse, opens on excessive circuit.

**ARCING** – a continuous spark jumping through the air. An arc can become self-sustaining by ionizing the air around it. An arc can reach an extremely high temperature instantly.

**FUSING** – when excessive current or arcing causes switch contacts to weld together, so the switch cannot be turned off.

**CRITICAL PARTS** – parts in a circuit which must be replaced by identical parts. On a schematic diagram, these parts will be identified by shaded areas or other notations.

**X-RAYS, ULTRAVIOLET, MICROWAVES** – types of potentially dangerous radiation. A technician should not work on equipment that produces these without special training and specific knowledge of the dangers involved with each piece of equipment.

**OZONE** – produced by very high voltages, x-rays and ultraviolet light. A sudden aroma of ozone around equipment that's not supposed to produce it is a warning to shut the equipment down and leave the area.

**BURN HAZARD** – prolonged contact with a surface that's 160 degrees Fahrenheit or hotter, the temperature of very hot coffee, will produce a burn. Some hazards:

- Heat sinks
- Soldering irons & solder
- Heat guns
- Hot glue guns
- Anything that is hot enough to glow
- Any kind of flame – things like alcohol burners are especially dangerous because the flame is hard to see

**FIRE PREVENTION** -

- Keep flammable material away from work area
- Store flammable things in approved metal cabinet

***Review page 7***

- Solvents used on the bench should be kept in push-top dispensers
- Don't have solvents and a hot soldering iron in the work area at the same time
- Don't shake hot solder into a wastebasket
- Don't smoke in the work area
- Run all the power on the workbench through a single switch that is turned off when you leave the area
- Keep a class C fire extinguisher nearby

**FIRE EXTINGUISHER** – the only type approved for electrical fires is a class C extinguisher. Other types should not be near the work area where people can get at them; they can make a fire worse or electrocute the people using them.

**CHEMICALS** – many chemicals can do damage when inhaled or spilled on skin. The damage often happens gradually and is only noticed when it's too late to do anything about it. There are usually several chemicals to do any job; choose the one that presents the least hazard. Read the labels. Note that solder fumes are a "dangerous chemical."

**AVOIDING DAMAGE TO VISION** -

- Keep safety glasses or goggles handy and use them.
- Always assume an optical fiber may be "live," even if you can't see any light. Infrared laser light can damage your eyes as easily as visible light.
- Keep an infrared light detector in the tool kit.

**AVOIDING DAMAGE TO HEARING** -

- Avoid loud noises. If it sounds annoyingly loud, it is probably doing permanent damage. Mid and high frequencies are worse than low frequencies. Short, sharp noises like gunshots are especially damaging.
- Wear ear protection in noisy environments. In a pinch, a wad of facial tissue in each ear is better than nothing. Don't share earplugs; you can share infections in the process.

**CLOTHING ISSUES** -

- If you work around moving machinery, don't wear anything that could get caught. This includes hair. Ties should be the clip-on type. Shirts should be short-sleeve.
- Remove rings and metal necklaces.
- Wear steel toed shoes if there's any chance something heavy could land on your feet.

**LABELS** – keep a selection of warning signs, blank tags and china markers in your vehicle.

**CHOKING HAZARDS** – don't chew gum. If you need lubrication, take a coffee break.

***Review page 8***

**CRT'S** – cathode ray tubes are charged up to 25,000 volts or more, and they have a high vacuum inside. Discharge before working on. Relieve the vacuum before discarding by breaking off the tip at the back. Handle carefully when out of the case; if you break the tube, glass will fly everywhere.

**VEHICLE** – perform regular maintenance. Secure ladders so they can't fly off, even in a collision.

**PHONE USE IN THE VEHICLE** - Limit cellphone use or pull over, and don't text while driving. If you must use the cellphone a lot, set it up so you can do it hands-free. Get in the habit of calling the shop before you leave the jobsite. This will also help you remember to note last-minute extras that you should charge for.

**DEALING WITH ONSITE HAZARDS** – keep several different kinds of gloves in the vehicle, including one for high voltages. Carry dog and hornet repellent sprays.

**FIRST AID KIT** – keep a basic kit, and keep it stocked. If anyone on the crew has an allergy or is diabetic, the kit should include appropriate treatments. Keep the kit stocked.

**MOUTH-TO-MOUTH RESCUSCITATION** – if someone is unconscious, use your lungs to fill theirs every 4-6 seconds. M2M training is recommended.

**CPR** – don't try it unless you're trained.

**HEIMLICH MANEUVER** – for choking, good descriptions are available on the web. Training is recommended.

**CUTS** – wash, compress until bleeding stops, apply topical antiseptic, bandage. Get stitches for large or deep cuts, or ones on joints that will flex.

**FIRST DEGREE BURNS** – outermost skin layer burned, red skin with some swelling. Hold under cool (not cold) water for 10-15 minutes, wrap loosely with sterile gauze and tape. Take oral painkiller. Do not apply ice, butter or ointment. See a doctor if infection develops.

**SECOND DEGREE BURNS** – first layer of skin burned through, splotchy red with severe swelling and blisters. Treat as for first degree burn and get medical attention reasonably soon. If the burned area is greater than 3 inches in diameter, get medical attention immediately.

**THIRD DEGREE BURNS** – skin is burned through and underlying muscle and tissue may be burned. Skin is black or dry and white. Make sure victim is not still in contact with burning material. Do not remove clothing unless it's smoldering. Call 911. If victim is unconscious, check for signs of breathing and begin resuscitation if necessary. If it is likely that the victim is suffering from smoke or carbon monoxide, tell the 911 operator. Elevate the burned parts above the heart if possible. Loosely cover the burned parts with gauze until help arrives; do not put anything else on the burn.

***Review page 9***

**FIRST AID TRAINING** – highly recommended. Even if you never have to use it, it could help you land a job.

**NATIONAL ELECTRICAL CODE** – published by the National Fire Protection Association, the universal reference for electrical safety standards.

## CHAPTER 3 – MATH

**DECIMAL SYSTEM** – a system based on the numbers 0 thru 9.

**DIGIT** – an individual number within a large number; for example, in "1,234," 1, 2, 3 and 4 are digits.

**DECIMAL PLACE** – a position within a large number that indicates the significance of a digit. For example, in "234," 4 means four, 3 means thirty, and 2 means two hundred. The places are called "ones," "tens," "hundreds" and so on.

**PLACE HOLDER** – a zero that occupies a place to preserve the digital significance of a larger number. For example, in "100" there are no tens or ones. Zeroes are put in those places so we will know the "1" is in the hundreds place.

**WHOLE NUMBERS** – also called INTEGERS, digits in the ones place and those to the left; complete numbers or "counting numbers."

**DECIMAL FRACTIONS** – numbers to the right of the ones place, signifying quantities smaller than 1.

**DECIMAL POINT** – a dot to the right of the ones place identifying the division between whole numbers and fractional numbers.

**SIGNIFICANT DIGITS** – the relative amount represented by a digit, based on its position within a larger number. In 234.56, "2" is the **MOST SIGNIFICANT DIGIT** and "6" is the **LEAST SIGNIFICANT DIGIT**.

**ORDER OF MAGNITUDE** – a very general approximation of the size of a number, whether in the neighborhood of 1, 10, 100 etc. Commonly used to express relative sizes: 3,000 is two orders of magnitude greater than 40.

**COMMON FRACTION** – a number above another number, separated by a horizntal line. The lower number is the **DENOMINATOR**, indicating how many parts something is divided by; the upper number is the **NUMERATOR**, indicating how many parts are actually present. In text, the horizontal line is replaced by a slash. For example, "3/4" or "$^{3}/_{4}$" means 3 pieces of something that's in 4 pieces.

**PROPER FRACTION** – a fraction signifying a quantity less than 1; that is, a fraction where the numerator is smaller than the denominator. ¼, $^{3}/_{16}$, $^{5}/_{8}$ are proper fractions.

***Review page 10***

**IMPROPER FRACTIONS** – a fraction signifying a quantity greater than 1, as in $^{17}/_{5}$. It is customary to convert an improper fraction to a **MIXED NUMBER** by converting the amount in excess of 1 to an integer, then stating the remainder as a fraction. $^{17}/_{5} = 3^{3}/_{5}$. On the other hand, you often have to convert a mixed number to an improper fraction to use it in calculations.

**DIVISION BY ZERO** – cannot be done. If any calculation involves division by zero, either there is an error or the calculation involves an impossible quantity.

**DECIMAL CONVERSION OF A FRACTION** – a fraction can be seen as a division operation; $^{3}/_{5}$ can be read as "3 divided by 5." To convert to a decimal fraction, simply perform the division. In this case, divide 3 by 5, giving a total of 0.6.

**INCREMENT** – a measured increase. Usually, an increase of 1, for example from 5 to 6, unless another amount is specified.

**DECREMENT** – a measured decrease, by 1 unless another amount is specified.

**PERCENTAGE** – hundredths of something. 1 is 1% of 100, 20 is 1% of 2,000.

**FACTORS** – the numbers that a larger number can be divided by; the numbers that can be multiplied together to get the larger number. The factors of 12 are 2, 2 and 3. A number that cannot be divided by any other numbers except 1 and itself is a **PRIME NUMBER**.

**REDUCING FRACTIONS** – stating a fraction in the smallest possible digits by finding numbers that both numerator and denominator can be factored by. $^{8}/_{24}$ can be reduced to $^{1}/_{3}$ by dividing numerator and denominator by 2, then 2, then 2.
denominator.

**RATIO** – the proportional relationship between two quantities, written as two numbers separated by a colon. If one number is three times as large as another, they have a 3:1 ratio.

**IRRATIONAL NUMBER** – a number that cannot be precisely written as a fraction. An irrational decimal number is indicated by dots as in 3.1416...

**TRUNCATION** – throwing away the least significant digits to simplify calculation. Since real-world quantities are seldom exact, decisions regarding how many digits to deal with are a routine part of electonic calculations.

**ROUNDING** – selecting the value of the least significant digit after truncating. If the most significant discarded digit is 5 or greater, round up – e.g. 2.5466 becomes 2.547. If 4 or smaller, round down.

**RECIPROCAL OF A NUMBER** – 1 divided by that number. The reciprocal of 5 is $^{1}/_{5}$ or, in decimal form, 0.2. A reciprocal can easily be found with a calculator by entering the number, then hitting the "1/" key. The result of multiplying a number by its reciprocal is always 1. This can be used as a way to check whether the division was done correctly. Zero does not have a reciprocal.

***Review page 11***

**RECIPROCAL METHOD OF DIVISION** – dividing any quantity by a number "N" is the same as multiplying it by the reciprocal of N, "1/N." For example, 8 divided by 4 is the same as 8 multiplied by 0.25.

**TOLERANCE** – how much the real value of something may differ from the specified value, usually stated as a percentage. A specified value of 1,000 with a 1% tolerance means the real value may be above or below 1,000 by as much as 10.

**ABSOLUTE NUMBER** – a number where quantity is specified but not sign, indicated by vertical lines on either side of a number. For example, |6| may mean either +6 or -6. It is assumed that an AC voltage quantity is an absolute number, and the vertical lines are usually omitted.

**POWER OF A NUMBER** – how many times a number is multiplied by itself. 6 x 6 x 6 is 6 to the $3^{rd}$ power.

**ROOT OF A NUMBER** – the number that must be multiplied by itself a certain number of times to get another number. 3 x 3 = 27; thus 3 is the $2^{nd}$ root of 9.

**SQUARE, CUBE** – special names given to $2^{nd}$ and $3^{rd}$ powers.

**SQUARE ROOT, CUBE ROOT** – special names given to $2^{nd}$ and $3^{rd}$ roots. These cannot be easily calculated by hand, a tech should keep a calculator with a square root function handy.

**EXPONENT** – a small number above and to the right of a regular number that indicates its power or root.

> **INTEGER EXPONENT** – identifies the power of a number. $4^3 = 4 \times 4 \times 4$.
>
> **FRACTIONAL EXPONENT** – identifies the root of a number. $9^{1/2}$ or $9^{0.5}$ is the square root of 9, which is 3. $256^{1/8}$ is the $8^{th}$ root of 256, which is 2.
>
> **NEGATIVE EXPONENT** – the same as the positive exponent of a reciprocal. $5^{-3}$ is $^1/_5 \times {}^1/_5 \times {}^1/_5$, which is $(^1/_5)^3$ or $0.2^3$.
>
> **"1" EXPONENT** – $N^1 = N$.
>
> **"0" EXPONENT** – $N^0 = 1$
>
> **EXPONENT OF 0** – zero to any power is zero.

**POWERS OF 10** – like any other exponents, but especially useful in decimal calculations. Each place in a decimal number signifies a power of ten. 1,000 is 10 x 10 x 10, or $10^3$. 1,111 is $10^3 + 10^2 + 10^1 + 10^0$.

**NUMBER OF ZEROES** – the number of zeroes, including leading zeroes for decimal fractions, is equal to the power.

***Review page 12***

**MULTIPLYING POWERS** OF 10 – several numbers consisting of 10 with exponents can be multiplied by adding the exponents. $10^6 \times 10^2 \times 10^{-3} = 10^5$.

**MULTIPLYING BY MOVING A DECIMAL POINT** – a number can be multiplied by "10 to some power" by moving the decimal point one place right or left per order of magnitude. To multiply by $10^1$, $10^2$, $10^3$ etc, move the decimal point *right* by 1, 2, 3 places etc. To multiply by $10^{-1}$, $10^{-2}$, $10^{-3}$ etc, move the decimal point left by 1,2,3 places etc.

**SCIENTIFIC NOTATION** – a way of expressing numbers as a digit and power of ten. The digit and the 10's are separated, then the tens are converted to exponential form: 3,000 = 3 x 1,000 = 3 x $10^3$. A number like 3,245 is represented by a "ones" digit, a decimal fraction, and a power of 10. 3,245 = 3.245 x 1,000 = 3.245 x $10^3$.

**MULTIPLYING NUMBERS IN SCIENTIFIC NOTATION** – multiply the numerical digits, then add the exponents of the powers of 10. 3 x $10^5$ times 2 x $10^{-3}$ = 6 x $10^{-2}$.

**PREFIXES** – word fragments placed before numbers to eliminate zeroes; e.g. 1,000 grams = 1 kilogram.

Each prefix represents three orders of magnitude difference from the adjacent ones. Between prefixes, we use 1, 10, 100 as in:

10 watts
100 watts
1 kilowatt
10 kilowatts
100 kilowatts
1 megawatt etc.

**CONVERTING BETWEEN PREFIXES** – to convert from a prefix to the next larger one, e.g. Mega to Giga, move the decimal point three places left. To convert to the next smaller one, e.g. Mega to kilo, move the decimal three places to the right. Thus 1 Megawatt is 0.001 Gigawatt.

**EQUATION** – a mathematical statement that says two things are the same, also, a relationship between two or more quantities. Each of the numbers in an equation is called a **TERM**; 2 + 2 = 4 has three terms.

**VARIABLE** – a letter that represents a number that may be unknown, or may be any number. Letters that are commonly used to represent specific quantities should not be used as variables, unless the variable actually represents the quantity. For example, "R" should not be used as a variable except when it actually represents resistance. Variables are also called **GENERAL NUMBERS**.

**FUNCTION** – a formula that describes a relationship between two quantities, often cause/effect, often stated in terms of variables. For example, "Y=3N" means that Y is 3 times N, and implies that any change in N will cause three times as much change in Y.

***Review page 13***

**ISOLATING THE UNKNOWN** – moving terms around in an equation so all the known quantities are on one side of the equal sign and the quantity we're trying to find is on the other. This is known as **SOLVING FOR** that quantity. When there are several quantities that are unknown or can be chosen, we can choose which one to solve for by how we move the terms around.

**MAINTAINING EQUALITY** – making sure an equation which is valid to start with is still valid after the terms are moved around. To do this, specific rules about moving terms must be followed. The most commonly used rules are listed at the end of this summary.

**INEQUALITIES** – numbers that are specifically larger or smaller than other numbers. A>B or B<A means A is greater than B or B is smaller than A. A>>B or B<<A means A is much greater than B or B is much smaller than A. By mathematical convention, >> or << means one number is so much smaller than the other that it can be ignored in calculations.

**X-Y GRAPH** – a 2-dimensional space where a function may be shown. There is a numbered, horizontal scale along the bottom of the graph, called the **X-axis**, and a vertical scale along the left side of the graph, called the **Y-axis**. The intersection of X and Y axes at the lower left corner, where quantities are both zero, is called the **origin**. Every point on the graph corresponds to a particular value of X and a particular value of Y. If every possible combination of X and Y for a function is pinpointed on the graph, the result is a solid line (usually) showing a visual representation of the function.

**METRIC CONVERSIONS** – ideally, these should be memorized. All conversions are approximate.

1 meter = 3.28 feet
1 meter = 1 yard + $3^{3}/_{8}$ inches
1 foot = 0.305 meter
1 centimeter = 0.394 inch
1 inch =2.54 centimeter
1 kilogram = 2.2 pounds
1 pound = 0.455 kilograms
1 gram = 0.035 ounce
1 ounce = 28.3 grams

**RULES FOR FRACTIONS**

**1.** You can do whatever you choose to the numerator, as long as you do the same thing to the denominator. Exception: you can't do anything that involves or results in division by zero.
**2.** Fraction times integer: multiply the numerator by the integer. Also works with fraction divided by integer.
**3.** Fraction plus fraction: convert one or both fractions so the denominators are the same, then add numerators. Also works with fraction minus fraction.
**4.** Fraction times fraction: multiply numerators, separately multiply denominators.
**5.** Fraction divided by fraction: invert the second fraction to find its reciprocal, then multiply.

***Review page 14***

**RULES FOR EQUATIONS**

**1.** You can do whatever you choose to one side ofan equation, as long as you do the same thing to the other side. Exception: you can't do anything that involves or results in division by zero.
**2.** If A=B, then B=A. The sides of an equation can change places.
**3.** If A=B, then A+N = B+N.
**4.** If A=B, then AxN = BxN.
**5.** To add when both sides have multiple terms, just add.
**6.** If AxB-C = D+E, then AxB-C+X = D+E+X.
**7.** To multiply a product, just multiply. AxB multiplied by C is AxBxC.
**8.** To multiply a sum, each term must be separately multiplied. A+B multiplied by C is AC + BC.
**9.** In mixed expressions like AxB+C, multiplication operations are performed first, then addition.
**10.** Parentheses are used where several terms are to be considered as one, where a certain operation must be performed first, or where the order of operations goes against normal rules. Example: in AxB+C, if B+C is to be performed first, the expression is written as Ax(B+C).
**11.** Where a number is multiplied by an expression with mixed addition and multiplication terms, multiply the addition terms separately, the multiplication terms together. Ax(B+C+DxE) = AxB + AxC + AxDxE.
**12.** In multiplication, the "x" sign can be left out. ABC means AxBxC. This is especially recommended when X could be confused with a variable.
**13.** Equivalent quantities can be substituted for each other. If A = BC, then A + N = BC + N.
**14.** Rules for addition also apply to subtraction. Rules for multiplication also apply to division.

## CHAPTER 4 – OHM'S AND WATT'S LAWS

**3 FORMS OF OHM'S LAW** – $I = V/R$, $V = IR$, $R = V/I$

**3 FORMS OF WATT'S LAW** – $P = VI$, $V = P/I$, $I = P/V$

**6 FORMS OF WATT'S LAW WITH RESISTANCE** –

$P = V^2/R$, $R = V^2/P$, $V = (PR)^{0.5}$

$P = I^2R$, $R = P/I^2$, $I = (P/R)^{0.5}$

**SHORTCUT FOR MOVING TERMS** – a term can be moved from the denominator on one side of an equation to the numerator on the other. This is valid only if an expression is a product of multiplied terms. It is not valid if any expression has an addition or subtraction operation.

$$\frac{ab}{ef} = \frac{cd}{gh} \qquad \frac{abg}{ef} = \frac{cd}{h} \qquad \frac{abg}{cef} \neq \frac{d}{h}$$

*Review page 15*

This is simply multiplying both sides of the equation by the same quantity without writing down all the steps. This kind of movement is the basic algebraic operation with Ohm's and Watt's Laws. The shortcut also applies where one side of the equation is not a fraction, since "N" can always be regarded as N divided by 1.

## CHAPTER 5 – COMPONENTS

**CLASSES OF MATERIALS** -
- Conductors, which conduct electricity
- Insulators, which do not conduct electricity unless their breakdown voltage is exceeded (this usually destroys the material)
- Semiconductors, whose conductivity can be manipulated

**CONDUCTORS USED FOR WIRES** – copper is by far the most common. Aluminum is used for long-distance, high-power transmission but is not used for building wiring.

**SOLDERABILITY** – whether a conductor can be soldered. For example, copper is easily soldered; aluminum is not.

**POOR CONDUCTORS** – used to control current.

**WIRE TYPES** -
- Bare or insulated
- Solid or stranded
- Tinned or untinned

**BARE WIRE** – used where nothing comes in contact with the wire, e.g. wire on electrical power poles

**INSULATED WIRE** – used for most applications. The insulation can either be a coating on the wire, traditionally called "varnish" but more often plastic, or an insulating **jacket** surrounding the wire.

**RUBBER INSULATION** – used where the wire will experience a lot of flexing; in most other applications plastic insulation is used.

**CLOTH INSULATION** – sometimes used for irons and other appliances which get hot and could melt plastic insulation. Cloth insulation is usually a layer of cloth over rubber or plastic.

**TEFLON INSULATION** – required in buildings where other materials might burn or give off poisonous fumes in a fire.

**STRANDED WIRE** – used where the wire will experience a lot of flexing, or where the wire has to be very flexible.

***Review page 16***

**THERMAL CONDUCTIVITY** – the ability to conduct heat from one place to another. Good electrical conductors tend to be good heat conductors; electrical insulators tend to be heat insulators.

**HEAT SINK** – a thermally conductive material that removes heat from an electrical part by transferring it to the air.

**SWITCH** – a device which can close or open a circuit. When a switch closes, it **makes**, when it opens, it **breaks**. A switch's most important limitations are the maximum current it can carry and the maximum voltage it can switch. These specifications are likely to be different for AC and DC circuits.

**POLES** – the number of separate switching circuits in a switch. A switch that closes and opens two separate circuits at the same time would be a double-pole switch.

**THROWS** – the number of closed positions in a switch. A switch that is open in one direction and closed in the other is a single-throw switch. One that makes a circuit in one direction and makes a different circuit in the other is a double-throw switch.

**SWITCH NOMENCLATURE** – the convention is, poles first, then throws: SPST means “single pole, single throw.” The most common switches are SPST, SPDT, DPST, DPDT. With switches that have more poles or throws, numbers are used: a 3-pole, 8-position switch would be 3P8T.

A switch can also be labeled “ON-OFF” or “ON-ON” or, for a 3-position double-throw switch with a center-off position, “ON-OFF-ON.”

**SNAP ACTION SWITCH** – one where the contacts make and break instantaneously, no matter how slowly the lever or toggle is moved. Used where a quick make and break are necessary to prevent contact arcing.

**BBM, MBB** – in a multiple-throw switch, BBM means “break before make,” in which one circuit is opened before the other is closed. MBB means “make before break,” in which the second circuit is closed before the first is open; for a moment, both circuits are closed. Most switches are BBM.

**MOMENTARY ACTION** – a switch that has only one normal rest position. When moved to the other position and released, it will automatically return to the first position. In labels, momentary positions are identified by parentheses: “(ON)-OFF.”

**NORMALLY OPEN, CLOSED** – in a momentary pushbutton or switched, the normal condition of the circuit. A normally-open pushbutton is open until you push it; a normally-closed button is closed until you push it. Double-throw pushbuttons and switches do not carry either designation because they have closed circuits in both positions: (ON)-ON.

**RELAY** – a switch operated not by a lever but by an electromagnet. The electromagnet may be operated by another switch, so when it closes the relay “relays” the closure to another part of the circuit. The major parts of a relay are:

***Review page 17***

- Coil – a coil of wire forming an electromagnet.
- Pole piece – a piece of iron in the center of the electromagnet. As well will see in chapter 11, this greatly increases the efficiency of the electromagnet.
- Armature – an iron piece which moves or pivots. When the electromagnet is energized, the armature is attracted to the pole piece.
- Spring – returns the armature to rest position when the electromagnet is de-energized.
- Contacts – equivalent to a switch's contacts. One (or more) contact is mounted on the armature so it moves when the armature moves.
- Frame – holds everything together.

Relays can have NO, NC or combination contacts, and more than one pole, just like switches.

**PULL-IN** – when a relay armature is pulled to the pole piece. This usually happens when the voltage across the coil is at least ¾ of its specified operating voltage.

**DROP-OUT** – when the armature returns to rest position. This usually happens when the voltage across the coil falls to around ¼ to $^1/_8$ of its specified voltage. In other words, once a relay is pulled in, it stays in until the coil voltage drops to a small fraction of its rated voltage.

**SOLENOID** – a term used for automotive starter relays.

**BIFURCATED CONTACTS** – an arrangement where each pair of contacts is split into two pairs. For the relay to fail to "make," both sets of contacts must fail at the same time. This greatly reduces the odds of failure.

**LATCH CIRCUIT** – a circuit whereby, once a relay pulls in, its coil is fed via its own contacts, so it stays pulled in. A NC pushbutton in the coil circuit is used to unlatch the relay. Widely used with machinery to prevent it from starting up by itself after a power failure.

**BUZZER** – a relay connected in an **astable** configuration so it constantly pulls in and drops out. Back-and-forth motion is called **oscillation**.

**FUSE** – a wire deliberately designed to melt and break a circuit when current becomes excessive. The wire is contained in a glass or ceramic shell for safety. The most important fuse characteristics are:

- Rated current – the maximum current a fuse will carry before blowing. This is somewhat dependent on ambient temperature and whether the fuse is well ventilated; thus, fuses are typically run at no more than 75% of their specified current.
- Rated voltage – the maximum voltage a fuse can safely control.
- Speed of operation – broadly divided into "fast-blow" and "slow-blow" categories. Fast-blow fuses operate 50 to 100 times faster than slow-blow fuses. The proper fuse depends on whether or not the circuit it is used in is able to/has to tolerate overcurrent for a significant period. For example, a motor may take 10X its normal current when first starting; a fast-blow fuse would stop it before it got up to speed. Fuses, of course, are not resettable; they blow once and you throw them away.

***Review page 18***

**CIRCUIT BREAKER** – like a fuse that can be reset and re-used. Most breakers are manually reset; some, like the thermal breakers in refrigerators, can reset themselves. Breakers can detect overcurrent either thermally or magnetically. Some breakers make use of both.

**CROWBAR CIRCUIT** – a monitoring circuit that, in the event of malfunction, deliberately shorts the power source to trip the breaker.

**RESISTOR** – a component containing a poor conductor to create a lumped resistance in a comparatively small package. Materials used are carbon, carbon film, metal film and resistance wire (nichrome or similar).

**TOLERANCE** – the degree to which a component's actual value may differ from its specified value. Usually stated as a percentage. Modern resistors typically have a specified tolerance no greater than 5%. This means the resistor value is no more than 5% higher or lower than specified.

**RESISTOR POWER RATINGS** – in electronic circuitry, resistors with leads are typically rated at 1/2W or more commonly 1/4W maximum power dissipation. Surface-mount resistors may have much lower power ratings. A resistor rated for 5W or more is typically called a **power resistor** and can be made as large as needed.

**SMT** - “surface mount” resistors (and, as we will see in later chapters, other components) which, instead of leads, have tabs that solder directly to the surface conductors of a printed circuit board.

**RESISTOR COLOR CODE** – a series of colored bands identifying at least two digits, a multiplier, and a tolerance. The complete chart is reproduced for printout at the end of this summary.

**VARIABLE RESISTOR** – a resistance whose resistance can be varied by means of a **tap** that can be placed at any point along the resistive element. Also called a **rheostat**. A tap which is made to be adjusted frequently is called a **wiper**.

**POTENTIOMETER** – abbreviated **pot**, a variable resistor with three connections; one at each end of the resistive element and one at the wiper. This allows the pot to be used as a variable voltage divider.

**TRIMMER** – a variable resistor connected to a fixed resistor to permit precise adjustment of overall resistance.

## CHAPTER 6 – SERIES CIRCUITS

**SERIES CIRCUIT** – a circuit where there is only one current path.

*Review page 19*

**CURRENT IN A SERIES CIRCUIT** – does not divide among resistances. All the current flows through all the resistances in turn. Current measures the same everywhere in the circuit.

**VOLTAGE IN A SERIES CIRCUIT** – divides among resistances. A portion of the total voltage appears across everys\ resistance. A particular resistor's resistance, as a percentage of the total, is proportional to the voltage drop across that resistor, as a percentage of the total:

$$\frac{V_{TOTAL}}{V_{RESISTOR\ N}} = \frac{R_{TOTAL}}{R_{RESISTOR\ N}}$$

This can be rearranged to find the voltage drop across a particular resistor:

$$V_N = \frac{R_N \times V_{TOTAL}}{R_{TOTAL}}$$

In that form, the equation is called **Kirchoff's Voltage Divider Law.**

**TOTAL RESISTANCE IN A SERIES CIRCUIT** – equals the sum of the individual resistances:

$$R_{TOTAL} = R_1 + R_2 + R_3 ... + R_N$$

The total resistance in a series circuit is always higher than any of the individual resistances.

**VOLTAGE DROP** – the voltage that appears across each resistance

**SUM OF VOLTAGE DROPS** – is equal to the supply voltage.

**KIRCHOFF'S VOLTAGE LAW** – the algebraic sum of all the voltages in a loop (including supply) is zero.

**VOLTAGE DIVIDER** – two or more resistors in series which divide the total voltage between them. The individual voltage drops are proportional to the individual resistances. They can be found by finding the current, then multiplying by each resistance. They can be found without knowing the current by applying Kirchoff's voltage divider law:

$$V_N = V_T R_N / R_T$$

**SERIES, SHUNT RESISTOR** – in a voltage divider, the series resistor is the one connected between the voltage input and output; the shunt resistor is the one connected between output and the zero reference point.

**POTENTIOMETER** – abbreviated "**pot**," a voltage divider where the ratio of series to shunt is variable. The tap can also be called a **wiper**. A potentiometer connected as a 2-terminal variable resistor is called a **rheostat**.

***Review page 20***

**TRIMMER** – a potentiometer or rheostat used to “trim” or precisely adjust the value of another resistor.

## CHAPTER 7 – PARALLEL CIRCUITS

**CURRENT IN A PARALLEL CIRCUIT** – divides among the resistances; some of the total current flows through each resistor.

**VOLTAGE IN A PARALLEL CIRCUIT** – does not divide. The same voltage appears across all resistances.

**BRANCH** – any one of the individual current paths in a parallel circuit represented by any one of the resistances.

**NODE** – a point where several wires are joined. Current flows into and out of the node. In calculations, incoming current is assigned a positive (+) sign and outgoing current a negative (-) sign.

**KIRCHOFF'S CURRENT LAW** – the algebraic sum of all the currents flowing into and out of a node is zero.

**TOTAL CURRENT** – is the sum of the current through all the individual resistances. Total current is always higher than the current in any branch.

**INDIVIDUAL CURRENTS** – are inversely proportional to individual resistances.

**TOTAL RESISTANCE** – the combination of all the parallel resistances. In a parallel circuit, total resistance is always lower than any of the individual resistances.

**PRODUCT OVER SUM FORMULA** – a way of finding the total resistance when you have two resistors in parallel:

$$R_{TOTAL} = \frac{R_1 \times R_2}{R_1 + R_2}$$

**RECIPROCAL FORMULA** – a way of finding total resistance when you have more than two resistors in parallel:

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots + \frac{1}{R_N}$$

**KIRCHOFF'S CURRENT DIVIDER RULE** – the current flowing through any resistor in a parallel circuit, as a percentage of the total current, is inversely proportional to its resistance as a percentage of the total:

*Review page 21*

$$\frac{I_{RESISTOR\ N}}{I_{TOTAL}} = \frac{R_{TOTAL}}{R_N}$$

which can be rewritten as:

$$I_N = \frac{I_{TOTAL} \times R_{TOTAL}}{R_N}$$

## CHAPTER 8 – SERIES/PARALLEL CIRCUITS

**SERIES-PARALLEL** – a circuit which has both series- and parallel-connected elements.

**ANALYZING A SERIES-PARALLEL CIRCUIT** – done by repeatedly replacing individual series and parallel parts of the circuit with equivalent resistances using formulas you learned for series and parallel circuits.

**LOADED VOLTAGE DIVIDER** – a voltage divider where the input-to-output ratio is not determined solely by the series and shunt divider resistors. The shunt resistor and the load must be treated as an equivalent parallel resistance.

**VOLTAGE DIVIDER EFFICIENCY** – total power consumed vs. power that actually gets to the load. Power consumed in the divider can be thought of as "overhead." Voltage dividers are inefficient, so they tend to be used only in low power applications.

## CHAPTER 9 – TEST EQUIPMENT AND METHODS

**VOLTMETER** –

- measures voltage
- is connected across a circuit
- should have as high a resistance as possible
- circuit must be powered up

**AMMETER** –

- measures current
- is connected into a circuit in series with the load
- should have as low a resistance as possible
- circuit must be powered up

*Review page 22*

**OHMMETER** –

- measures resistance
- places a voltage across a resistance and measures resulting current
- circuit must be powered down
- requires a power source, usually a 1.5V battery.
- must be “zeroed” to cancel test lead resistance. Most digital meters do not permit zeroing, in which case the user shorts the test leads together once to measure their resistance, then subtracts that resistance from every measurement in the future.

**WATTMETER** –

- measures power
- is connected both in series with and across the load
- circuit must be powered up

**MULTIMETER** –

- combines voltage, current and resistance measurement in one device

**INDIRECT CURRENT MEASUREMENT** – voltage drop across a known resistance is measured to find current.

**INDIRECT POWER MEASUREMENT** – current and voltage are separately measured, or one is measured if the other is known; resulting power is calculated.

**ANALOG METER** – usually consists of a **d'Arsonval movement**. Reading is indicated by the position of a pointer.

**SHUNT** – a low resistance across an ammeter that passes most of the current around the meter. This permits the meter to measure much higher currents than it could measure on its own.

**DIGITAL METER** – voltage is measured via a digital counting and timing unit; result is displayed by a numeric readout. Digital ammeters measure voltage drop across a shunt. A digital meter requires a battery or other power source.

**MULTIPLIER RESISTORS** – are used in a voltmeter to permit the meter to read a number of different voltage ranges.

**OHMS PER VOLT** – multiplier resistors increase the overall resistance of an analog voltmeter. The total resistance changes as the voltage measurement ranges are changed. A typical value is 20,000 ohms per volt, meaning that when the meter is set to read 1V full scale, its resistance is 20,000 ohms. When it's set for 10V its resistance is 200,000 ohms, when set for 100V it's 2 megohms etc. Meter loading must be taken into account when measuring voltages in high-resistance circuits.

**VTVM and FET METER** – a meter with a current amplifier between the multiplier resistances and the meter movement. This isolates the meter movement from the input and permits the

***Review page 23***

use of very high resistance multipliers, essentially eliminating the meter loading problem. Requires a power source, usually a battery in modern meters. Digital meters are always FET input meters.

**HIGH VOLTAGE PROBE** – a test lead with a very high-value resistor built in, and a highly voltage-resistant construction, used with a regular voltmeter to measure extremely high voltages.

**WAVEFORM ERROR** – most meters only measure AC voltages accurately when the wavform is a sine wave. To accurately measure other wave shapes, an RMS-measuring meter must be used.

**FREQUENCY ERROR** – most meters are calibrated to read AC voltages accurately when the frequency is 60Hz. Higher frequencies, especially with inexpensive digital meters, will not read correctly. We will deal with frequencies and waveforms in great detail in EM2.

**HOLD BUTTON** – found on many digital meters, captures a measurement so the user can read it after the meter is disconnected from the circuit.

**WHEATSTONE BRIDGE** – a device which permits the accurate measurement of resistances. One of few good ways to measure very low resistances.

**CONTINUITY TESTER** – a simplified ohmmeter, checks whether a circuit has continuity or not. Usually makes a sound to indicate continuity, so the user can watch what they're testing.

**CABLE TESTER** – a sophisticated continuity tester. Tests for continuity between corresponding pins at each end of the cable. Also tests for continuity between adjacent pins, indicating a fault.

**BATTERY TESTER** – a voltmeter specifically calibrated to measure the most common batteries. A good one will load the battery to show what it can do when actually putting out current.

**RESISTOR SUBSTITUTION BOX** – a number of resistors in a box, selectable by switch and connected to terminals. Used to quickly insert a resistor in a circuit for test purposes.

**MEGGER** – checks the integrity of wire insulation by applying a high voltage and looking for any trace of current leakage. “Megger” is a trademark.

## CHAPTER 10 – BATTERIES AND SUPPLIES

**CELL** – consists of two electrodes of different materials and an electrolyte that the electrodes are immersed in. Chemical reactions between the electrodes and the electrolyte produce a voltage difference across the electrodes.

*Review page 24*

**BATTERY** – a number of cells connected in series.

**PRIMARY BATTERY** – a battery that cannot be recharged.

**SECONDARY BATTERY** – a battery that can be recharged.

**RECHARGING** – is done by connecting the battery across a higher voltage source, which forces current backwards through the battery.

**COMMON BATTERY TYPES** –

- carbon zinc (primary)
- alkaline (usually primary)
- lead-acid (secondary)
- mercury (primary, obsolete
- NiCd (secondary)
- NiMH (secondary)
- Li-ion (secondary)

**CELL VOLTAGES** –

- carbon-zinc and alkaline, 1.5V. lead-acid a bit higher
- NiCd and NiMH, 1.2V
- Li-ion, up to 3.7V

**BATTERY RATINGS** – batteries are rated in amp-hours or milliamp-hours, the current the battery can deliver for an hour before running down. Alkaline, lead-acid and NiMH are the standouts.

**ENERGY DENSITY** – how much energy a battery stores per unit of volume. Lead-acid is good, though comparatively heavy. The standouts are Alkaline, NiMH and Li-ion.

**DISCHARGE CURVE** – the voltage across a carbon-zinc, lead-acid or alkaline battery falls as the battery is discharged, making it easy to tell how much charge is left. The voltage across Ni-Cd, NiMH and Li-ions does not fall significantly until the battery is almost completely discharged. Estimating remaining charge requires a sophisticated, usually microprocessor based circuit.

**CHARGING** - lead-acid and rechargeable alkaline batteries can be recharged with a simple charger. Since their voltage rises with charge, with a properly designed charger a point will be reached where the battery voltage equals the charger voltage, and then no more charging will occur. NiCd, NiMH and Li-ion batteries require “smart” chargers that look for small changes in the voltage. Alternately, they can be charged at a low current.

**BATTERIES CONNECTED IN SERIES** – amp-hour rating is the same as one cell; voltages add up. All cells should be identical.

**BATTERIES CONNECTED IN PARALLEL** – voltage is the same as one cell, amp-hour ratings add up. All cells should be the same chemical type.

***Review page 25***

## CHAPTER 11 – MAGNETISM

**A MAGNET** –

- always has a North and a South **pole**
- has a **field**
- attracts magnetic materials and attracts/repels other magnets

**MAGNETIC MATERIALS** – are attracted to magnets and can be made into magnets, a process called **magnetization**. By far the most magnetic material is iron, either by itself or in combination with other elements.

**NONMAGNETIC MATERIALS** – are not attracted to magnets and cannot be magnetized to any significant degree. Magnetic fields pass through them as if they were not there.

**MAGNETIC FIELDS** –

- completely surround a magnet. This is true even of a horseshoe magnet; though the field is concentrated between the ends, some of the field surrounds the magnet.
- are directional and form a complete loop; they travel outside the magnet from North to South pole, then return to the North pole inside the magnet.

**MAGNETIC LINES OF FORCE** –

- are a way to conceptualize a magnetic field
- are shaped to show the flow of the field
- have arrows to show the direction of the field
- are more or less numerous to show the strength of the field

**MAGNETIC FLUX** – the strength of the total field, represented by the number of lines of force.

**FLUX DENSITY** – the strength of the field in a particular area, represented by the number of lines of force passing through one square centimeter at right angles.

**DOMAINS** – one theory of magnetization holds that magnetic materials are made of huge numbers of tiny bar magnets pointing in all directions, and magnetization occurs when an external magnetic field causes these domains to line up in the same direction. The other theory holds that magnetization is caused by electron spin.

**NATURAL MAGNET** – a magnet that is found in nature, made by natural processes.

**ARTIFICIAL MAGNET** – a magnet that is manufactured by placing a piece of magnetic material in a strong external field.

**HARD IRON** – iron whose magnetization is hard to change. Magnetizing it requires a very strong external field, but once it is magnetized, it keeps its magnetism.

***Review page 26***

**SOFT IRON** – iron whose magnetization is easy to change. It easily becomes magnetized in response to an external field, but once the field is removed, it loses its magnetism.

**PERMANENT MAGNET** – a magnet that keeps its magnetism.

**TEMPORARY MAGNET** – a magnet that loses its magnetism as soon as the external magnetizing field is removed.

**INDUCTION** – when a piece of soft iron touches a magnet, it becomes a magnet. The word "induction" describes this phenomenon.

**PERMEABILITY** – the ease with which a magnetic field is established in a material. Air is used as the reference and assigned a permeability of 1. By comparison, soft iron has a permeability of 10,000.

**RELUCTANCE** – the difficulty with which a magnetic field is established in a material; in other words, the opposite of permeability.

**SATURATION** – when a magnetic material becomes as strongly magnetized as it is possible to get. The domain theory would say this is when all the domains are lined up in one direction.

**RETENTIVITY** – also called residual magnetism, the magnetism that remains after the external magnetizing field is removed. A permanent magnet has high retentivity. A temporary magnet ideally has none.

**COERCIVITY** – how strong a reverse magnetic field must be to return a magnetized material to an unmagnetized state. This has important implications in disk drives, where old data must be overwritten by new data.

**ELECTROMAGNETISM** – magnetism generated by an electric current. Any time electrons move, a magneit field is created. This field is present even if there are no magnetic materials present, because it is not the material but the movement of electrons that generate the field. Copper is a nonmagnetic material, but if it has a current flowing through it, there will be a magnetic field around it.

**RIGHT HAND RULE** – a way to determine the direction of the lines of force that surround a wire when current flows through it. The right hand rule is used with conventional current. If we switch to electron flow, negative to positive, we switch to the left hand.

**COIL** – a wire formed into loops which are stacked to concentrate the magnetic field. Each loop is called a turn. The more turns, the greater the magnetism for a given amount of current.

**CORE** – what's in the center of the coil. A wire coil alone is an air-core magnet. A coil wound on a piece of soft iron is an iron-core magnet. For a given current, the iron-core magnet is several orders of magnitude stronger, because iron has a much higher permeability than air.

***Review page 27***

**MAGNETIC CIRCUIT** – similar to an electric circuit, a closed path for lines of force completely within magnetic material. Most devices, like motors, relays and buzzers, cannot be closed paths, but their efficiency is increased if they are formed to guide the lines of force in a path that is as close to a closed circuit as possible.

**MAGNETIC ATTRACTION VS. DISTANCE** – follows a roughly invers square function. Force is proportional to the inverse of the square of distance. In plain language, magnetic force falls off very quickly as the distance between a magnet and whatever it is pulling or pushing on increases. Thus magnetism works much better at close range.

**SOLENOID** – an electromagnet/armature arrangement where the armature is partially inside the coil. A solenoid can be designed to modify the inverse square function, spreading the force vs. distance curve out over a longer range of armature movement.

**FLYBACK** – the high voltage spike that occurs when the circuit delivering current to an electromagnet coil is suddenly broken. This spike can reach tens of thousands of volts.

***Review page 28***

## *Basic units chart*

*A line has been added for "Energy." Note that "E" means EMF to electronics people and energy to physicists, another reason we more often use "V." And in physics, "W" means "work."*

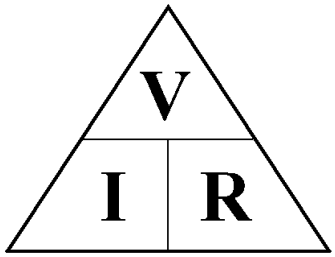
| PROPERTY | SYMBOL | UNIT | SYMBOL | FUNCTION |
|---|---|---|---|---|
| EMF, Electro-Motive Force | E or V | Volt | V | Force that makes current flow |
| Current | I | Ampere (Amp) | A | Flow of electrons |
| Resistance | R | Ohm | Ω | Limits current |
| Power | P | Watt | W | Work, E x I |
| Energy | E | Joule, Watt-Second | J W-S | Power x Time, P x T |

*Prefixes*

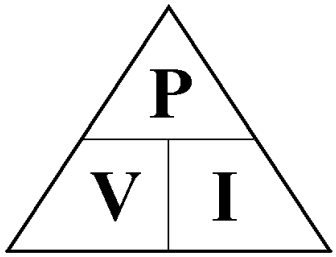
| Quantity | Decimal Number | Power | Prefix | Abbrev. |
|---|---|---|---|---|
| Trillion | 1,000,000,000,000 | $10^{12}$ | "Tera" | T |
| Billion | 1,000,000,000 | $10^{9}$ | "Giga" | G |
| Million | 1,0000,000 | $10^{6}$ | " Mega" | M |
| Thousand | 1,000 | $10^{3}$ | " kilo" | k |
| One | 1 | $10^{0}$ | | |
| Thousandth | 0.001 | $10^{-3}$ | " milli " | m |
| Millionth | 0.000001 | $10^{-6}$ | " micro" | μ |
| Billionth | 0.0000000001 | $10^{-9}$ | " nano" | n |
| Trillionth | 0.0000000000001 | $10^{-12}$ | " pico " | p |

Larger ↑ ↓ Smaller

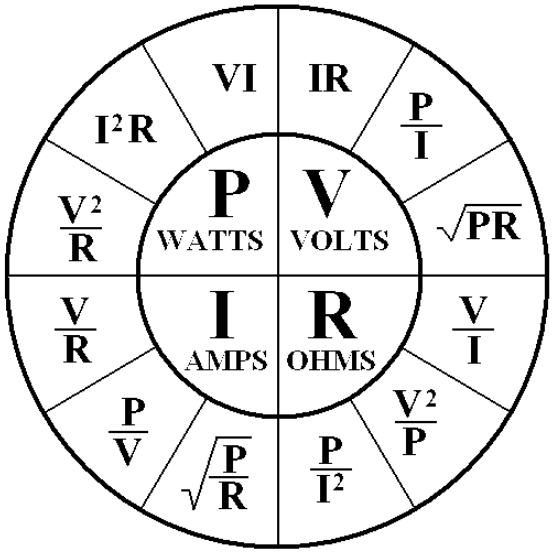
*Review page 29*




Ohm's Law Memory Aid




Watt's Law Memory Aid




Ohm's & Watt's Laws

## *Resistor Color Code*

| COLOR | NUMBER BAND VALUE | NUMBER OF ZEROES | RANGE OF RESISTANCES | TOLERANCE |
|---|---|---|---|---|
| BLACK | 0 | 0 | 10-99 | 1% |
| BROWN | 1 | 1 | 100-990 | 2% |
| RED | 2 | 2 | 1K-9.9K | |
| ORANGE | 3 | 3 | 10K-99K | |
| YELLOW | 4 | 4 | 100K-990K | |
| GREEN | 5 | 5 | 1M-9.9M | |
| BLUE | 6 | 6 | 10M-99M | |
| VIOLET / PURPLE | 7 | 7 | NOT USED | |
| GREY | 8 | | NOT USED | |
| WHITE | 9 | | NOT USED | |
| SILVER | | 0.01X | 0.1-0.99 | 10% |
| GOLD | | 0.1X | 1-9.9 | 5% |

**METRIC CONVERSIONS**

1 meter = 3.28 feet
1 meter = 1 yard + $3^{3}/_{8}$ inches
1 foot = 0.305 meter
1 centimeter = 0.394 inch
1 inch =2.54 centimeter

1 kilogram = 2.2 pounds
1 pound = 0.455 kilograms
1 gram = 0.035 ounce
1 ounce = 28.3 grams

Voltage in a series circuit $$\frac{V_{TOTAL}}{V_{RESISTOR\ N}} = \frac{R_{TOTAL}}{R_{RESISTOR\ N}}$$

Voltage across a particular resistor in a series circuit $$V_N = \frac{R_N \times V_{TOTAL}}{R_{TOTAL}}$$

Product over sum formula $$R_{TOTAL} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Reciprocal Formula $$R_{TOTAL} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3 \ldots} + \frac{1}{R_N}$$

Voltage divider law $$V_N = V_T\ R_N / R_T$$

***End of EM1 review***

# EM1 PRACTICE EXAMS

Print these out and put them in a folder. Take the exams one chapter at a time, after you've read through the chapter and the review enough to be confident that you know the material. Answers for all exams are listed together, after the last exam.

Note that some chapters have a *lot* of questions. I've heard different opinions about this; some people are afraid this will be intimidating to the student. My feeling is that there is no reason to arbitrarily limit the number of questions, since you're free to not answer them all if you don't feel like it. But I'd suggest doing them all, and also going back and reviewing until your knowledge is rock solid. Besides, you've paid for this study guide, might as well get your money's worth.

Using a calculator and the charts and memory aids printed in the review is “legal.”

## CHAPTER 1 – BASIC ELECTRICITY

1. Current is:
   A. the flow of voltage
   B. the flow of electrons
   C. the flow of protons
   D. the flow of power

2. Voltage is:
   A. the force that moves electrons
   B. the unit of measure of power
   C. power multiplied by current
   D. current multiplied by time

3. Resistance is:
   A. present in all conductors
   B. essentially infinite in insulators
   C. useful to control the flow of current
   D. all of the above

4. Power is:
   A. the push that moves electrons
   B. voltage times resistance
   C. voltage times current
   D. current times resistance

5. In a circuit, if voltage is raised and resistance is held constant, current will:
   A. not change
   B. increase
   C. decrease
   D. become unstable

6. In a circuit, if resistance is raised and voltage is held constant, current will:
   A. not change
   B. increase
   C. decrease
   D. become unstable

7. True or false: in the absence of voltage, current will not flow.
   A. true
   B. false

8. True or false: in the presence of voltage, current will always flow.
   A. true
   B. false

9. In a circuit, electrons flow:
   A. from a battery to a lamp
   B. from the positive terminal of a voltage source to the negative terminal
   C. from the negative terminal of a voltage source to the positive terminal
   D. in the absence of resistance

10. In the positive current convention, current is imagined to flow:
   A. into space
   B. from the positive terminal of a voltage source to the negative terminal
   C. from the negative terminal of a voltage source to the positive terminal
   D. across an open circuit

## CHAPTER 2 – SAFETY

1. The universally acknowledged authority on electrical safety standards is:
   A. the New York electrical code
   B. each equipment manufacturer's safety instructions
   C. the National Electrical Code from the NFPA
   D. the standards established by your employer

2. A current of 0.02 amp or more through the body is dangerous because:
   A. it can cause a permanent personality change
   B. it causes muscles to lock up
   C. it leaves a burn on your skin
   D. it can bring on joint arthritis

3. According to the electrical code, the highest DC voltage that is safe to handle directly is:
   A. 10V
   B. 30V
   C. 50V
   D. 70V

4. According to the code, the highest AC voltage that is safe to handle directly is:
   A. 12V
   B. 25V
   C. 30V
   D. 50V

5. According to the code, in wet conditions the highest voltage that is safe to handle directly is:
   A. 12V AC or DC
   B. 12V AC, 30V DC
   C. 10V AC, 25V DC
   D. 25V AC, 50V DC

6. A voltage that is higher than those listed above:
   A. must be contained so people cannot accidently come in contact with it
   B. is illegal
   C. must be identified by red warning tags
   D. must have a fast-blow fuse in the circuit

7. A current of 0.1A through the body:
   A. tickles
   B. constitutes a significant drain on the power source
   C. is illegal
   D. is lethal

8. When working with voltages higher than those listed in questions 2-4, you should:
   A. wear safety goggles
   B. work with one hand in your pocket
   C. put a red tag on the circuit breaker
   D. discharge the power line to Earth ground

9. An inverter:
   A. converts a low voltage to a high voltage
   B. is often designed to run on batteries
   C. can create a dangerous voltage inside a piece of equipment
   D. all of the above

10. In AC power wiring, the black wire is:
   A. hot
   B. common
   C. chassis ground
   D. there is no rule about this

11. In AC power wiring, the chassis ground wire is:
   A. blue
   B. green
   C. red
   D. orange

12. A hot chassis unit:
   A. is 160 degrees Fahrenheit or hotter
   B. is found in high powered equipment
   C. is directly connected to one side of the power line
   D. is illegal

13. A unit that is not normally hot-chassis may become hot-chassis through:
   A. failure of a component such as the hash filter
   B. being dropped on the floor
   C. being plugged into too high a voltage
   D. being removed from its insulating case

14. To be sure a unit is not hot-chassis, before working on it one should:
   A. look for a label on the back
   B. wiggle the power cord where it enters the unit to see if it comes loose
   C. measure the resistance between both sides of the power plug and the chassis
   D. connect it in series with a 100W bulb and see if it lights up

15. Does turning off a unit's power switch or pulling a fuse reliably disconnect the circuitry from the power cord?
   A. yes
   B. no

16. Phantom voltage is:
   A. voltage that comes in on the antenna cable
   B. voltage that's stored in power supply capacitors
   C. the voltage that a meter puts across the circuit when measuring
   D. voltage that appears across the speaker output when no speaker is connected

17. Before working on a unit, it should be unplugged and power supply capacitors discharged to:
   A. the unit's chassis
   B. Earth ground
   C. the chassis of the nearest piece of test equipment
   D. power supply capacitors should not be discharged

18. A ground-fault interrupter or GFI outlet disconnects power when it senses:
    A. excessive voltage
    B. excessive current
    C. an imbalance between current out and current return
    D. a current on the green wire that exceeds 15 amps

19. In dry air, electricity can jump roughly:
    A. one inch
    B. one centimeter
    C. one foot
    D. one yard

20. If you see vacuum tubes inside a piece of equipment, you know for certain that:
    A. It's at least 20 years old
    B. it is a television transmitter
    C. it's an esoteric, expensive piece of gear
    D. it has potentially lethal voltages inside

21. Fuses and breakers are rated in:
    A. amps
    B. ohms
    C. volts
    D. watts

22. You should not wear metal jewelry when working on electronic equipment because:
    A. it may be damaged
    B. it can get connected into the circuit
    C. it is unprofessional
    D. it can affect the equipment's operation

23. Parts that are shown on diagrams with shading around them:
    A. are special high-precision parts
    B. can be expected to get hot in normal operation
    C. must be ordered directly from the manufacturer
    D. must be replaced with identical parts

24. Microwave equipment often produces levels of radiation that are dangerous to technicians working on it:
    A. true
    B. false

25. The sudden odor of ozone indicates:
    A. that an abnormally high voltage, amount of ultraviolet light or amount of microwaves is present
    B. that the technician working on the unit is in danger
    C. that power should be turned off and the area should be evacuated and ventilated
    D. all of the above

26. Strong ultraviolet light can permanently damage vision:
    A. true
    B. false

27. A heat shrink gun can start a fire if:
    A. it's aimed at something flammable while it's running
    B. only if something flammable touches it
    C. you cover over its air intake
    D. it can't start a fire; it's essentially a hair dryer

28. Before a CRT is discarded, you should:
    A. break off the neck
    B. discharge it
    C. remove hazardous materials
    D. discharge it and break off the little glass piece on the end

29. Hearing damage:
    A. may occur in any noisy environment
    B. may not become evident until decades after the damage is done
    C. cannot be repaired
    D. all of the above

30. A necktie worn around machinery should be:
    A. hand-knotted
    B. clip-on
    C. thrown over your shoulder
    D. covered by a long-sleeved sweater

31. The proper type of extinguisher for use on an electrical fire is:
    A. class A
    B. class B
    C. class C
    D. class D

32. When assisting a victim of shock, the most important thing is:
    A. begin CPR immediately
    B. treat any burns
    C. begin mouth-to-mouth immediately
    D. not become a victim of shock yourself

33. Should an untrained person perform CPR?
    A. yes, might be needed, play it safe
    B. no, you can cause more damage
    C. yes, it reflects well on your presence of mind in an emergency.
    D. no, it's against union rules.

34. Should burned clothing be pulled away from a 3rd-degree burn?
   A. yes
   B. only if it's smoldering
   C. no
   D. yes, if it's a synthetic material and has melted

## CHAPTER 3 – MATH

Questions 1-5 refer to the following quantities:

**A: 2/7**
**B: 3**
**C: 0.65**
**D: |2|**

1. Which quantity is a regular fraction?
   A
   B
   C
   D

2. Which quantity is an integer?
   A
   B
   C
   D

3. Which quantity is a decimal fraction?
   A
   B
   C
   D

4. Which quantity is a whole number?
   A
   B
   C
   D

5. Which quantity is an absolute number?
   A
   B
   C
   D

6. |6| means:
   A. +6
   B. -6
   C. +6 or -6
   D. 1/6

7. A>>B may be taken to mean:
   A. A is smaller than B
   B. A is a bit larger than B
   C. A is so much larger than B that B doesn't matter
   D. over the course of time, A turns into B

8. A 3-to-1 ratio is written:
   A. 3 - - 1
   B. (3,1)
   C. 3:1
   D. 3%1

9. A leading zero may be added to a decimal fraction to:
   A. avoid error when a number is photocopied
   B. increase precision
   C. facilitate multiplication by moving the decimal point
   D. emphasize that the “ones” place doesn't have anything in it

10. Converting the fraction $^{16}/_{24}$ to the fraction $^{2}/_{3}$ is called:
   A. rationalizing the fraction
   B. factoring the fraction
   C. reducing the fraction
   D. conversion to a mixed number

11. Which pair of numbers are different by two orders of magnitude?
   A. 6 and 16
   B. 3 and 45
   C. 235 and 19,000
   D. 23 and 32

12. In the number 2,835 the most significant digit is:
   A. 2
   B. 8
   C. 3
   D. 5

13. The factors of 625 are:
   A. 6, 2 and 5
   B. 5 and 125
   C. 6 and 25
   D. 5, 5, 5 and 5

14. Which of the following is not a prime number?
   A. 7
   B. 9
   C. 11
   D. 13

15. An irrational number is:
    A. a number that can't be true, given the circumstances
    B. a number that can't be expressed as a common fraction
    C. a number that can't be expressed as a decimal fraction
    D. a fraction whose numerator is larger than its denominator

16. $^{5}/_{8}$ x 6 =
    A. $^{30}/_{8}$, i.e. $3^{3}/_{4}$
    B. $^{30}/_{48}$, i.e. $^{5}/_{8}$
    C. $^{11}/_{14}$
    D. $^{5}/_{48}$

17. ¾ x $^{5}/_{8}$ =
    A. $^{30}/_{8}$, i.e. $3^{3}/_{4}$
    B. $^{15}/_{12}$, i.e. $1^{1}/_{4}$
    C. $^{15}/_{32}$
    D. $^{20}/_{24}$, i.e. $^{5}/_{6}$

18. The reciprocal of 8 is
    A. 0.8
    B. $^{1}/_{8}$
    C. 0.2
    D. 2.3

19. Stated decimally, the reciprocal of 10 is
    A. 0.1
    B. 0.01
    C. $^{1}/_{10}$
    D. 100

20. 1,3579 truncated to two places is:
    A. 1.3
    B. 1,3000
    C. 1,4000
    D. 79

21. $10^{3}$ x $10^{5}$ is:
    A. $10^{8}$
    B. $10^{15}$
    C. 10815
    D. $10^{2}$

22. The square root of 2, written as an exponent, is:
    A. $2^{-2}$
    B. $2^{1.4}$
    C. $2^{0.5}$
    D. 1.4159...

23. 0.0001 written as a power of 10 is:
    A. $10^{4}$
    B. $10^{-4}$
    C. $10^{1/4}$
    D. $10^{.0001}$

24. 2,300 in scientific notation is:
    A. 23 x $10^{3}$
    B. 2,300 x $10^{3}$
    C. 2.3 x $10^{2}$
    D. 2.3 x $10^{3}$

25 “Mega-” means:
    A. one hundred
    B. one thousand
    C. one million
    D one billion

26. “Milli-” means:
    A. one millionth
    B. one thousandth
    C. one hundredth
    D. a quantity measured in millimeters

27. 15,000V is:
    A. 15kV
    B. 1.5kV
    C. 15MV
    D. 15mV

28. Without regard to whether you'd actually do the problem this way, is the following algebraic progression “legal?”

    **1. A=1/BC**
    **2. AC = 1/B**
    **3. C = 1/AB**
    **4. AB = 1/C**
    **5. B = A/C**

    A. yes
    B. no

29. If not, which step is wrong?
    A. all are correct
    B. 3
    C. 4
    D. 5

30. (3+2)6 =
    A. 36
    B. 15
    C. 30
    D. $^{1}/_{6}$

31. What kind of function is this?

    **x: 2, 4, 6, 8, 10**
    **y: 4, 16, 36, 64, 100**

    A. $y = x^{2}$
    B. $x = y^{2}$
    C. y = x + 2
    D. y = x/2

32. 1 inch = approximately:
A. 100MM
B. 2.54CM
C. 0.4CM
D. 0.254 meter

## CHAPTER 4 – OHM'S LAW

You may use the triangle and circle visual aids. All answers may be truncated to 3 places.

1. You have a flashlight with a 1.5V battery and an incandescent lamp that draws 0.2A. What is the filament resistance?
A. 3Ω
B. 75Ω
C. 7.5Ω
D. 0.133Ω

2. How much power does the lamp in question 1 consume?
A. 3W
B. 11.25W
C. 0.75W
D. 0.3W

3. How much current flows when a 470Ω resistor is connected across a 9V battery?
A. 52.2mA
B. 0.172A
C. 19.1mA
D. 4,230mA

4. A wire with a resistance of 0.3Ω is carrying a current of 15A. What will the voltage drop between the ends of the wire be?
A. 4.5V
B. 5V
C. 1.5V
D. 20.25V

5. How many watts will be dissipated by the wire in question 4?
A. 67.5W
B. 1.35W
C. 4.5W
D. 6.08W

6. A 100Ω resistor is rated to dissipate up to 30W. What is the maximum voltage that can be applied across the resistor without burning it out?
A. 33.3V
B. 54.8V
C. 30V
D. 9V

7. A 470Ω resistor is rated to dissipate up to 1/4W. How high must the current get before we have to move up to a 1/2W resistor?
A. 117.5mA
B. 2.3A
C. 1.88A
D. 23mA

8. What is the resistance of a 120V, 100W incandescent lamp?
A. 83.3Ω
B. 144Ω
C. 14.4Ω
D. 110Ω

9. The remote door latch mechanism in an apartment building requires a minimum of 20VDC to operate. At that voltage, it draws 1/2A. What is its resistance?
A. 10Ω
B. 200Ω
C. 40Ω
D. 5Ω

10. The power source for the door latch in question 9 puts out 24V. What is the limit to the resistance the wire between the power source and latch can have before the latch will stop operating?
A. 8Ω
B. 32Ω
C. 2Ω
D. 64Ω

## CHAPTER 5 – COMPONENTS

1. Electrically, materials are broadly divided into the following three classes:
A. metals, plastics, ceramics
B. good conductors, poor conductors, insulators
C. conductors, insulators, semiconductors
D. AC, DC, combination of AC and DC

2. Wiring in buildings and electronic equipment is almost always:
A. aluminum
B. iron
C. copper
D. silver

3. Oxidation of a metal:
A. forms a (usually) nonconductive coating
B. is a chemical reaction of the material and oxygen
C. must be removed before soldering
D. all of the above

4. "Dielectric constant" means"
   A. the resistance of a material per unit of thickness
   B. the voltage breakdown of a material per unit of thickness
   C. the current limit of a material per unit of thickness
   D. the power handling capability of a material per unit of thickness

5. A piezoelectric material:
   A. is an insulator
   B. flexes when a voltage is applied across it
   C. generates a voltage when it is flexed
   D. all of the above

6. A semiconductor:
   A. is a good conductor
   B. is a poor conductor
   C. is an insulator
   D. can be any of the above

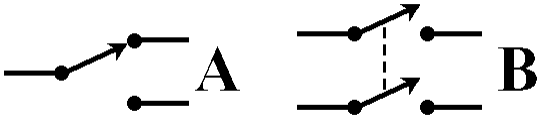
7. The semiconductor most commonly used in electronics is:
   A. germanium
   B. silicon
   C. carbon
   D. quartz

8. Stranded wire is:
   A. a bundle of thin wires
   B. a single wire with no insulation
   C. several separately insulated wires
   D. a wire that is connected to several points in a circuit

9. Tinned wire:
   A. is made of tin
   B. is usually copper wire, coated with tin
   C. is a tin alloy
   D. copper wire with a tin oxide insulating jacket

10. The switch shown at "A" below is a:
   A. SPST
   B. SPDT
   C. DPST
   D. DPDT

11. The switch shown at "B" below is a:
   A. SPST
   B. SPDT
   C. DPST
   D. DPDT




12. If you want to buy a switch with momentary action that rests in the center and makes one circuit in one direction, makes another circuit in the other direction, and no circuit in the center rest position, you would look for one labeled:
   A. ON-OFF-ON
   B. (ON)-ON-(ON)
   C. ON-(OFF)-ON
   D. (ON)-OFF-(ON)

13. A pushbutton which is a closed circuit except when your finger is pushing it, when it becomes an open circuit, is:
   A. (ON)-OFF
   B. NO
   C. NC
   D. ON-(ON)

14. A relay is:
   A. an electromagnetically operated switch
   B. an overcurrent protection device
   C. a voltage splitter
   D. a charge storage device

15. A benefit of using a relay would be:
   A. switching a large current with a small switch
   B. switching many poles with a single pole switch
   C. switching a large current at a distance without running heavy wires
   D. all of the above

16. The moving part of a relay is called the:
   A. pole
   B. armature
   C. coil
   D. frame

17. Bifurcated contacts are used to:
   A. increase reliability
   B. increase current handling capacity
   C. increase speed of operation
   D. reduce arcing

18. A buzzer is:
   A. a relay wired in a latch configuration
   B. a relay wired in an astable configuration
   C. a relay that repeatedly shorts the power supply
   D. a relay where the contacts are loosely attached

19. A fuse is:
   A. a piece of silicon in a glass tube
   B. a comparatively small-diameter wire
   C. an electromagnet
   D. a fixed voltage drop

20. What makes a fuse blow is:
A. excessive resistance
B. excessive power
C. excessive current
D. excessive voltage

21. Using Ohm's and Watt's Laws, find the appropriate fuse to protect a 120V, 1kW space heater. Assume the fuse must be oversized by 20% to avoid blowing needlessly.
A. 8.3A
B. 10A
C. 12A
D. 14.4A

22. On a 5% resistor, the fourth color band identifies:
A. temperature-related drift
B. tolerance
C. power handling ability
D. manufacturer

23. The color code for a 680-ohm, 5% resistor would be:
A. blue, gray, brown, silver
B. gray, blue, brown, gold
C. blue, gray, brown, gold
D. blue, brown, gray, silver

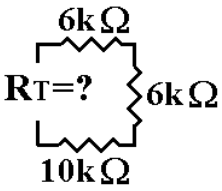
24. The minimum and maximum possible actual resistances of the resistor in question 23 are:
A. 646Ω, 714Ω
B. 612Ω, 748Ω
C. 68Ω, 6.8kΩ
D. 580Ω, 780Ω

25. A rheostat is:
A. a high-power resistor
B. an extremely precise (tight tolerance) resistor
C. a variable resistor
D. a surface-mount resistor

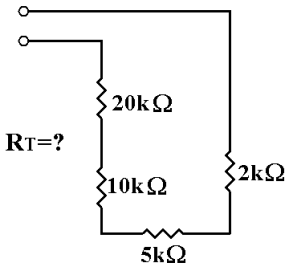
26. A potentiometer is:
A. a resistor with a nonlinear taper
B. a variable voltage divider
C. a voltage meter
D. a sensitive relay

## CHAPTER 6 – SERIES CIRCUITS

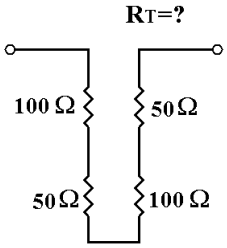
1. What is the total resistance of the circuit at right?
A. 16kΩ
B. 22kΩ
C. 2.3kΩ
D. 360kΩ




2. What is the total resistance of the circuit at right?
A. 31.4kΩ
B. 1.17kΩ
C. 100kΩ
D. 37kΩ




3. What is the total resistance of the circuit at right?
A. 300Ω
B. 75Ω
C. 33.4Ω
D. 400Ω




4. In a series circuit, _____ divides among resistances, but _____ is the same at every point in the circuit.

A.Power, Resistance
B. Power, Voltage
C.Voltage, Current
D Current, Voltage

5. If a string of holiday lights goes out completely because one bulb burned out, the lights are wired in _____.
A. Parallel
B. Series
C. Series Parallel combination
D. Tandem

6. The statement “the Algebraic Sum of all voltages in a loop must equal zero” is called _____.
A. Kirchhoff’s Voltage Divider Law
B. Ohm’s Law
C. Kirchhoff’s Current Divider Law
D. Faraday’s Law.

7. A series circuit contains _____ for current to flow.
A. A single path
B. Multiple paths
C. Current does not flow in a circuit; voltage flows
D. Two paths

8. The formula $R_T = R_1 + R_2 + R_3 + \ldots R_n$ is used to calculate _____.

A. Total reactance in a series circuit
B. Total voltage in a series circuit
C. Total reactance in a parallel circuit
D. Total resistance in a series circuit

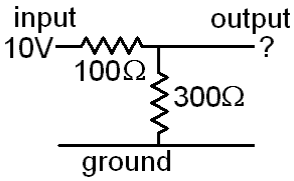
9. Proper polarity of the meter is not important when applying Kirchhoff's Law to circuit voltage measurements.

A. True
B. False

10. When using a volt meter or multi-meter to measure voltage drops across resistances in a circuit, typically the _____ lead is the positive lead of the meter and the _____ lead is the negative lead of the meter.

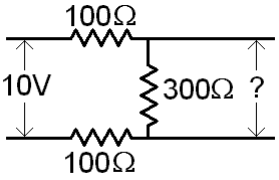
A. Black, Red
B. Red, Green
C. Red, Black
D. Green Red

11. In the circuit at right, what is the voltage between the output and ground?




A. 8V
B. 7.5V
C. 6.7V
D. 3.3V

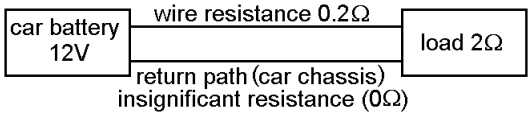
12. In the circuit at right, what is the voltage across the right-hand resistor?




A. 3V
B. 5V
C. 6V
D. 8V

13. In the system below, how much voltage gets to the load?

A. 12V
B. 11V
C. 10.9V
D. 10V



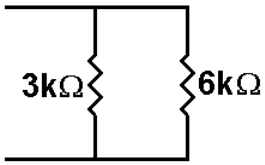

14. In the system above, how much power is lost in the wires?

A. 18W
B. 5.45W
C. about 4.4W
D. about 6W

## CHAPTER 7 – PARALLEL CIRCUITS

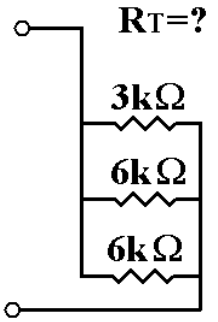
1. In the circuit at right, what is the total resistance?

A. 1kΩ
B. 2kΩ
C. 9kΩ
D. 18kΩ

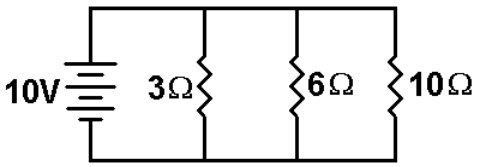



2. In the circuit at right, what is the total resistance?

A. 750Ω
B. 1.5kΩ
C. 15kΩ
D. 36kΩ




3. In the circuit below, what are the voltage drops across the resistors going from left to right?



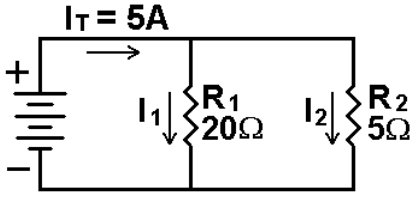

A. 3V, 6V, 10V
B. 3.3V, 1.67V, 1V
C. 1.57V, 3.16V, 5,26V
D. 10V, 10V, 10V

4. In the circuit of figure 3, how much current flows through each resistor going from left to right?

A. 3A, 6A, 10A
B. 3.33A, 1.67A, 1A
C. $^1/_3$A, $^1/_6$A, $^1/_{10}$A
D. 0.526A, 0.526A, 0.526A

5. Calculate the branch currents through $R_1$ and $R_2$ for the circuit below::

A. 20A, 5A
B. 1A, 4A
C. 4A, 1A
D. cannot be calculated from data given



6. In the circuit of figure 5, what is the battery voltage?

A. 20V
B. 25V
C. 100V
D. 5V

7. In a parallel circuit, _____ divides through the circuit resistances, but _____ is the same across any parallel resistance.

A. power, resistance
B. power, voltage
C. voltage, current
D. current, voltage

8. If all other bulbs on a string of Christmas lights stay on when one bulb in the string burns out, the lights are wired in _____.

A. parallel
B. series
C. series Parallel combination
D. tandem

9. The statement *"The algebraic sum of all currents entering and exiting a node must equal zero"* is called _____.

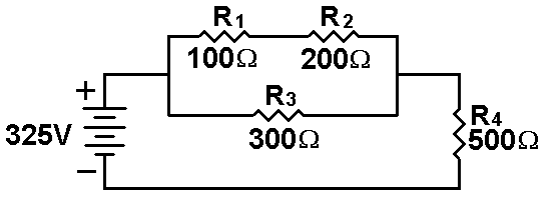
A. Kirchhoff's Voltage divider Law
B. Ohm's Law
C. Kirchhoff's Current Divider Law
D. Faraday's Law

10. A parallel circuit contains _____ for current to flow.

A. a single path
B. two paths
C. current does not flow in a circuit; voltage flows
D. multiple paths

## CHAPTER 8 – SERIES-PARALLEL CIRCUITS

Questions 1-4 reference the circuit below.




1. What is the equivalent resistance of the circuit, $R_{EQ}$?

A. 650Ω
B. 7.5Ω
C. 25Ω
D. 250Ω

2. What is the voltage drop across R4?

A. 250V
B. 33.3V
C. 75V
D. 50V

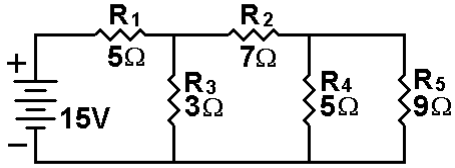
3. What is the current through R3?

A. 300mA
B. 75mA
C. 250mA
D. 25mA

4. What is the voltage drop across R2?

A. 25V
B. 50V
C. 75V
D. 325V

Questions 5-10 reference the circuit below.




5. What is the total current, $I_T$?

A. 1.54A
B. 2.05A
C. 2.54A
D. 10.35A

6. What is the voltage drop across R1?

A. 10.25A
B. 15V
C. 3.25V
D. 1.49V

7. What is the current through R2?

A. 465mA
B. 299mA
C. 1.49mA
D. 327mA

8. What is the voltage drop across R4?

A. 4.75V
B. 1.49V
C. 3.21V
D. 10.24V

9. What is the current through R5?

A. 166nA
B. 167mA
C. 166mA
D. 16.7mA

10. What is the wattage dissipated by R3?
    A. 7.53W
    B. 21W
    C. 2.21W
    D. 30.7W

## CHAPTER 9 – TEST EQUIPMENT AND MEASUREMENTS

1. A “basic meter movement” is essentially a(n)
    A. Ammeter
    B. Ohmmeter
    C. Voltmeter
    D. Multimeter

2. An analog ammeter has
    A. low internal resistance
    B. high internal resistance
    C. a battery inside
    D. no moving parts

3 An analog Ohmmeter has
    A. a linear scale
    B. high impedance
    C. a battery inside
    D. no moving parts

4. Multimeters measure
    A. voltage drop
    B. current flow
    C. circuit resistance
    D. all the above

5. Parallax error is due to
    A. circuit loading
    B. viewing angle
    C. incorrect range
    D. too much current

6. A DVM provides
    A. accurate measurements
    B. ease of use
    C. digital readout
    D. all the above

7. An advantage of a VOM is
    A. accuracy
    B. V, I, R can be measured with one meter
    C. no batteries required
    D. rugged meter movement

8. Touching the tips of the test leads pins with your fingers while measuring resistance on a circuit without power applied
    A. gives a higher than normal reading
    B. shows a lower reading than actual value
    C. shorts out the circuit
    D. is a shock hazard

9. The Ohms/volt rating of a analog voltmeter affects
    A. circuit loading
    B. accuracy of meter movement
    C. voltage readings
    D. the type of probe used

10. A high voltage probe contains
    A. a high value shunt
    B. a low resistance path
    C. a large multiplier resistor
    D. a small bleeder resistor

11. To measure current flow
    A. connect a voltmeter in series with power on
    B. connect an ohmmeter in series with power off
    C. connect an ammeter in series with power on
    D. connect an ammeter in parallel with power on

12. To measure voltage
    A. connect a voltmeter in parallel with power on
    B. connect an ohmmeter in series with power off
    C. connect a voltmeter in series with power off
    D. connect an ammeter in parallel with power off

13. To measure resistance
    A. connect a voltmeter in parallel with power off
    B. connect an ohmmeter in series with power off
    C. connect a voltmeter in series with power on
    D. connect an ohmmeter in parallel with power off

14. To measure power
    A. connect a voltmeter in parallel with power on
    B. connect an ammeter in series with power on
    C. connect a wattmeter in series with power on
    D. A and B above

15. You should be careful not to touch the leads tips when measuring resistance to avoid
   A. a parallel current path thru your body
   B high voltages present
   C. low current from the meter
   D. frying the circuit under test.

16. To measure very high voltage
   A. a megger is used
   B. a high voltage multiplier probe is used
   C. a shunt is used
   D. a series load is used

17. To measure high current a(n)
   A. megger is used
   B. high voltage multiplier probe is used
   C. external shunt is used
   D. series load is used

18. Safely precautions when measuring high voltage include
   A. wearing metal watches and rings
   B. removing metal watches and rings
   C. keeping one hand in your pocket
   D. B and C

19. The technician must use the most care when measuring:
   A. low ohms
   B. low current
   C. high voltage
   D. low voltage

20. If an ohmmeter has a zero-adjust pot, but you cannot get a zero reading when shorting the leads together, you should
   A. replace the battery
   B. keep one hand in your pocket
   C. use a shunt
   D. use a multiplier

## CHAPTER 10 – BATTERY SUPPLIES

1. A single battery cell
   A. creates a potential between two electrodes made of different materials
   B. stores chemicals that make electricity
   C. has a voltage of 1.2 to 1.5V in most cases
   D. all of the above

2. A 12V carbon zinc battery:
   A. is 8 cells connected in series
   B. is 12 cells connected in parallel
   C. is 8 cells connected in parallel
   D. is one 12V cell

3. A primary battery:
   A. can be recharged
   B. requires a “smart” charger
   C. cannot be recharged
   D. maintains the same voltage until almost completely discharged

4. If you draw 0.3A from a 5A-H battery, how long will it take to run down?
   A. 1.5 hours
   B. 5 hours
   C. 17 hours
   D. 8 hours

5. If you connect six 1.5V, 300mA-H batteries in series, what will be the total voltage and amp-hour rating?
   A. 9V, 300mA-H
   B. 1.5V, 1.8A-H
   C. 18V, 1.5A-H
   D. 6V, 450mA-H

6. If you connect six 1.5V, 300mA-H batteries in parallel, what will be the total voltage and amp-hour rating?
   A. 9V, 300mA-H
   B. 1.5V, 1.8A-H
   C. 18V, 1.5A-H
   D. 6V, 450mA-H

7. When charging a NiCd or NiMH battery without a smart charger, what is the maximum safe charge current?
   A. half the A-H rating
   B. one third the A-H rating
   C. one tenth the A-H rating
   D. twice the A-H rating

8. What should be done with a carbon-zinc battery that has run down?
   A. recharge it
   B. promptly remove it from equipment
   C. turn it end for end to reverse the polarity
   D. return it to the manufacturer under warranty

9. Which cell type can put out more than 3 volts?
   A. lead-acid
   B. NiMH
   C. Li-ion
   D. Alkaline

10. For a given size, which cell type stores the most energy?
    A. Li-ion
    B. NiCD
    C. Alkaline
    D. Carbon-Zinc

## CHAPTER 11 – MAGNETISM

1. What is magnetism commonly referred to as?
    A. the force in which objects are either attracted or repelled from one another
    B. the force in which objects are only attracted to one another.
    C. the force which causes objects to become non-polarized.
    D. the force in which objects are only repelled from one another.

2. Two types of machinery that could not operate without magnetism are motors and generators.
    A. true
    B. false

3. What black mineral ore is considered a natural magnet?
    A. oil
    B. magnetite
    C. onyx
    D. obsidian

4. Magnetite's ability to always point in one direction caused it to be called:
    A. lodestone
    B. ballast
    C, dragstone
    D. pointerstone

5. *Reluctance* is defined as:
    A. the ability of a material to retain magnetism.
    B. the opposition a material presents to induced magnetic lines of force.
    C. the ease with which magnetic lines of force distribute themselves throughout the material.
    D. the amount of magnetism which remains in a temporary magnet.

6. The strength of an induced electromagnetic field upon a conductor or coil is called:
    A. magnetomotive Force
    B. electrostatic Force
    C. electro-mechanical Force
    D .electromagnetic Force

7. What can the right-hand rule quickly identify?
    A. the direction for the lines of force surrounding a current-carrying conductor.
    B. the direction for reluctance in a current-carrying conductor.
    C. the direction for retentivity in a current-carrying conductor.
    D. the direction for residual magnetism in a current-carrying conductor.

8. Which statement is false?
    A. a magnet always has a North and South pole.
    B. a magnet's field completely surrounds it.
    C. lines of flux go in the South to North direction.
    D. a permanent magnet has high retentivity.

9. Saturation occurs when:
    A. a magnetic field reverses
    B. a magnetic field is neutralized
    C. two magnets touch each other
    D. the magnetic material is completely magnetized.

10. An electromagnet can be made stronger by:
    A. increasing the number of turns in the coil
    B. putting a piece of soft iron in the middle
    C. increasing the current through the coil
    D. any or all of the above

11. As a magnet is moved closer to a piece of magnetic material, the force of attraction:
    A. does not change
    B. changes linearly
    C. changes with the inverse square of distance
    D. reaches saturation

12. Flyback occurs when:
    A. magnetic material reaches saturation
    B. an electromagnet's circuit is broken
    C. two like poles are brought together
    D. a temporary magnet is allowed to return to a nonmagnetized state

## EM1 PRACTICE QUIZ ANSWERS

### Chapter 1, Basic Electricity

1-B 2-1 3-D 4-C 5-B 6-C 7-A 8-B 9-C 10-B

### Chapter 2, Safety

1-C 2-B 3-C 4-C 5-A 6-A 7-D 8-B 9-D 10-A 11-B 12-C
13-A 14-C 15-B 16-B 17-A 18-C 19-A 20-D 21-A
22-B 23-D 24-B 25-D 26-A 27-A 28-D 20-D 30-B
31-C 32-D 33-B 34-B

### Chapter 3, Math

1-A 2-B 3-C 4-B 5-D 6-C 7-C 8-C 9-A 10-C 11-
C 12-A 13-D 14-B 15-B 16-A 17-C 18-B 19-A
20-C 21-A 22-C 23-B 24-D 25-C 26-B 27-A 28-B
29-D 30-C 31-A 32-B

### Chapter 4, Ohm's and Watt's Laws

1-C 2-D 3-C 4-A 5-A 6-B 7-D 8-B 9-C 10-A

### Chapter 5, Components

1-C 2-C 3-D 4-B 5-D 6-D 7-B 8-A 9-B 10-B 11-
C 12-D 13-C 14-A 15-D 16-B 17-A 18-B 19-B
20-C 21-B 22-B 23-C 24-A 25-C 26-B

### Chapter 6, Series Circuits

1-B 2-D 3-A 4-C 5-B 6-A 7-A 8-D 9-B 10-C 11-B
12-C 13-C 14-D

### Chapter 7, Parallel Circuits

1-B 2-B 3-D 4-B 5-B 6-A 7-D 8-A 9-C 10-D

### Chapter 8, Series-Parallel

1-A 2-A 3-C 4-B 5-B 6-A 7-A 8-B 9-C 10-A

### Chapter 9, Meters and Measurements

1-A 2-A 3-C 4-D 5-B 6-D 7-B 8-B 9-A 10-C 11-C
12-A 13-D 14-D 15-A 16-B 17-C 18-D 19-C 20-A

### Chapter 10, Battery Supplies

1-D 2-A 3-C 4-C 5-A 6-B 7-C 8-B 9-C 10-A

### Chapter 11, Magnets

1-A 2-A 3-B 4-A 5-B 6-A 7-A 8-C 9-D 10-D 11-C
12-B

***End of EM1 Practice Quiz***